

NASA Technical Memorandum 4211

## Directory of Research Projects

### *Planetary Geology and Geophysics Program*

Henry Holt, *Editor*  
*NASA Office of Space Science and Applications*  
*Washington, D.C.*



National Aeronautics and  
Space Administration  
Office of Management  
Scientific and Technical  
Information Division

1990



## INTRODUCTION

This directory of research projects provides information about currently funded scientific research within the Planetary Geology and Geophysics (PGG) Program. The directory consists of the proposal summary sheet from each proposal funded under the PGG Program during fiscal year 1990, covering the period from October 1, 1989 through September 30, 1990. The summary sheets provide information about the research project including: title, principal investigator, institution, summary of research objectives, past accomplishments, and proposed new investigations. This directory is intended to inform scientists in the PGG Program about other research projects supported by the program and can also be utilized by others as a PGG Program information source.

The research projects funded under the PGG Program include investigation over a broad range of topics including geological and geophysics studies of: terrestrial planets and satellites; outer planet satellites and rings; comets and asteroids; planetary interiors; lithosphere-atmosphere relationships; impact cratering processes and chronologies; planetary surface modification by fluvial, aeolian, periglacial, masswasting, and volcanic processes; planetary structure and tectonics; multispectral and radar remote sensing; and solar system dynamics. Also, cartographic and geologic maps of the solid surfaces of planets and satellites are produced and distributed.

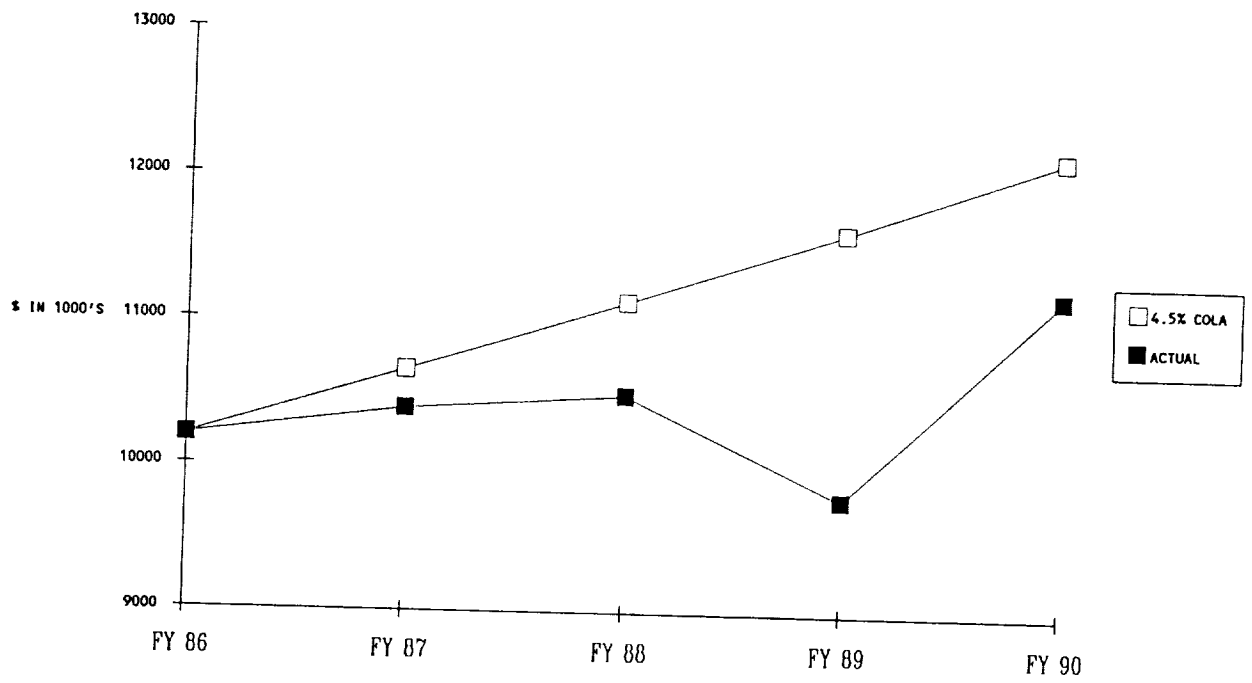
Statistical information about the PGG Program is presented the next two pages. The following four pages are an alphabetical listing of all program principal investigators. The remainder of the directory consists of the project summaries arranged alphabetically by the PI's last name.

For additional information about the Planetary Geology and Geophysics Program, contact one of the persons below:

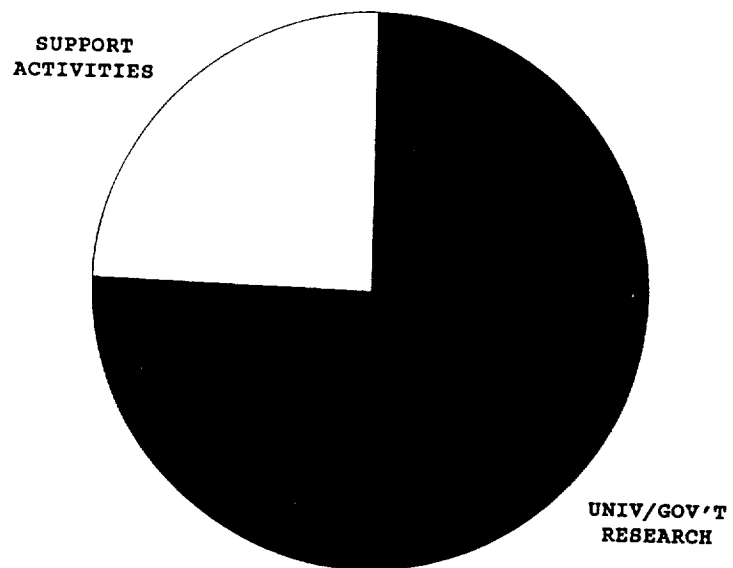
Ted A. Maxwell  
Discipline Scientist, Planetary  
Geology and Geophysics Program  
Code EL  
NASA Headquarters  
Washington, DC 20546

Joseph M. Boyce  
Manager, Planetary  
Geosciences Programs  
Code EL  
NASA Headquarters  
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# PLANETARY GEOLOGY AND GEOPHYSICS PROGRAM

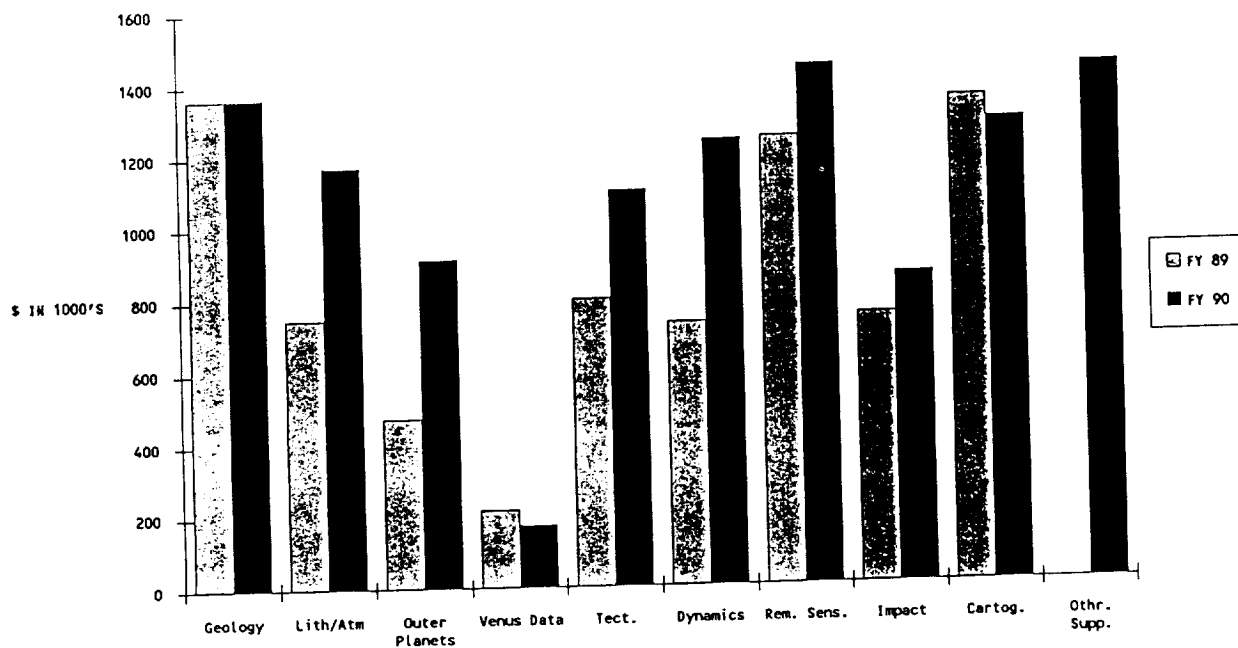


## SUPPORT TASK BREAKDOWN

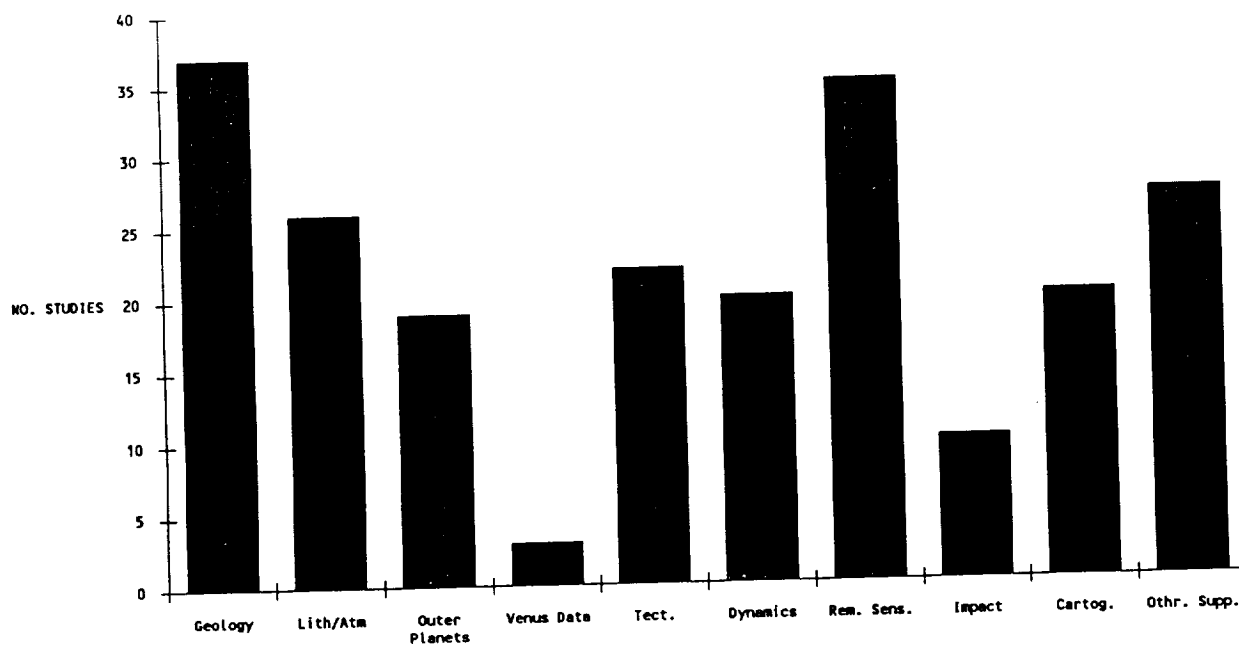




# FUNDING BY CATEGORY

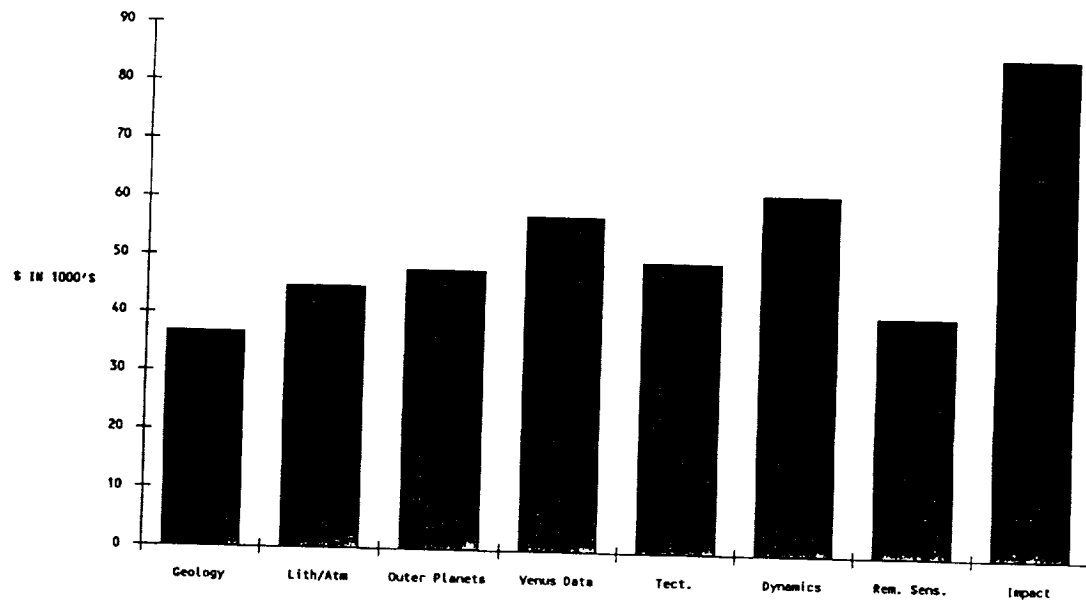


# NO. INVESTIGATIONS BY CATEGORY

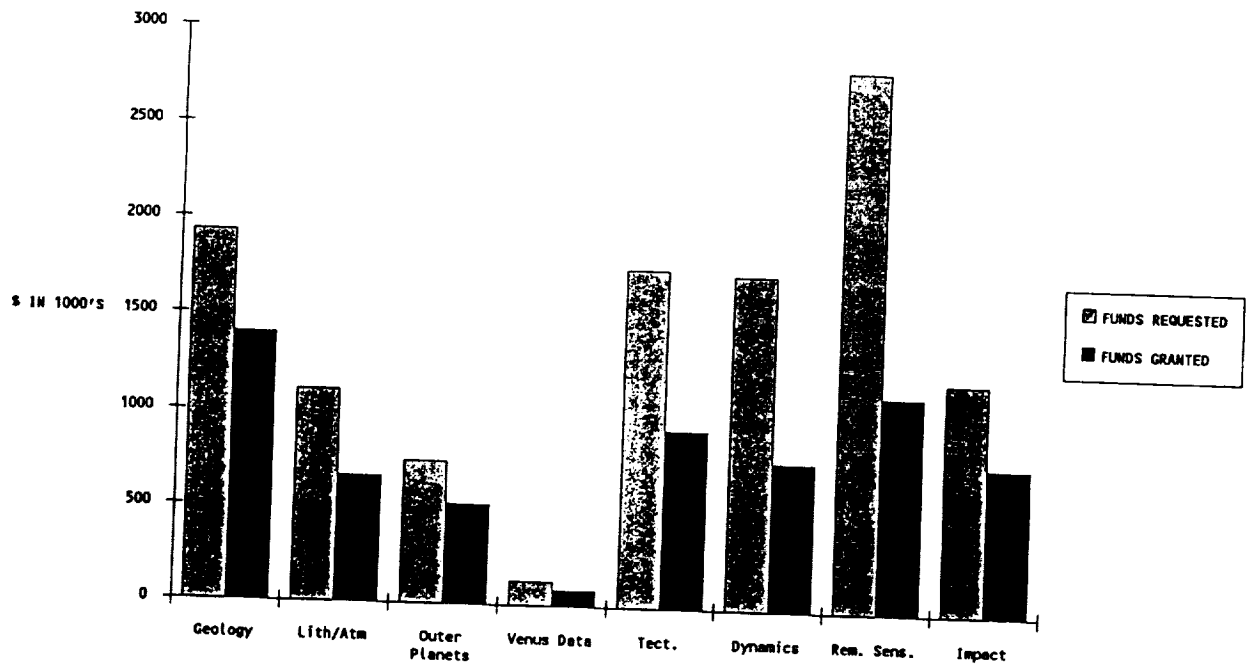


ORIGINAL PAGE IS  
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AVERAGE GRANT/CONTRACT SIZE



FUNDING SOUGHT VS. GRANTED



PG&G PROGRAM: SUPPORTED PROPOSALS IN FY 90

INVESTIGATOR

INSTITUTION

Adams, John B.	U WA
Ahrens, Thomas J.	Cal Tech
Arvidson, Raymond E.	Wash. U
Baker, Victor R.	U AZ
Baloga, Stephen M.	JPL
Banerdt, W. Bruce	JPL
Batson, Raymond	USGS, Flagstaff
Bell, Jeffrey F.	U HI
Boring, John W.	U VA
Boss, Alan	Carnegie Inst. of Wash.
Bridges, Frank	U CA, Santa Cruz
Brown, Robert H.	JPL
Buratti, Bonnie	JPL
Burns, Joseph A.	Cornell
Burns, Roger G.	M.I.T.
Butterworth, Paul S.	NASA/GSFC
Campbell, Donald B.	Cornell
Carr, Michael H.	USGS, Menlo Park
Christensen, Philip R.	AZ St U
Clark, Roger N.	USGS, Denver
Clow, Gary D.	USGS, Menlo Park
Condit, Christopher	U MA, Amherst
Craddock, Robert	Smithsonian
Crisp, Joy A.	JPL
Crumpler, Larry S.	Brown
Cuzzi, Jeffrey	NASA ARC
Davies, Merton E.	RAND Corp.
Davis, Donald R.	PSI
Davis, Philip A.	USGS Flagstaff
De Hon, Rene A.	NE LA U
Dermott, Stanley F.	U FL Gainesville
Durham, William B.	LLNL
Elston, Wolfgang E.	U NM
England, A. W.	U MI
Eshleman, Von R.	Stanford
Esposito, Larry W.	U CO
Fanale, Fraser P.	U HI
Fink, Jonathan	AZ St U
French, Richard G.	Wellesley
Frey, Herbert	NASA GSFC
Gaffey, Michael J.	RPI
Gaskell, Robert W.	JPL
Gehrels, Tom	U AZ
Goguen, Jay D.	JPL
Golombek, Matthew P.	JPL

PG&G PROGRAM: SUPPORTED PROPOSALS IN FY 90

INVESTIGATOR

INSTITUTION

Gooding, James L.	NASA/JSC
Gradie, Jonathan C.	U HI
Greeley, Ronald	AZ St U
Greenberg, Richard J.	U AZ
Hager, Bradford	M.I.T.
Hapke, Bruce	U Pittsburgh
Harris, Alan W.	JPL
Hartmann, William	PSI
Hawke, Bernard Ray	U HI
Head, James W., III	Brown
Holsapple, Keith A.	U WA
Holt, Henry E.	N AZ U
Hood, Lon L.	U AZ
Howard, Alan D.	U VA
Jakosky, Bruce M.	U CO
Jeanloz, Raymond	U CA, Berkeley
Johnson, Robert E.	U VA
Johnson, Torrence V.	JPL
Kaula, William	UCLA
Kieffer, Hugh H.	USGS, Flagstaff
Kieffer, Susan W.	AZ St U
King, John S.	SUNY, Buffalo
King, Trude	USGS, Denver
Kirk, Randolph L.	USGS, Flagstaff
Komar, Paul D.	OR St U
Lebofsky, Larry A.	U AZ
Lee, Steven W.	U CO
Levy, Eugene H.	U AZ
Lissauer, Jack J.	SUNY, Stony Brook
Lucchitta, Baerbel	USGS, Flagstaff
Lucey, Paul G.	U HI
Lunine, Jonathan I.	U AZ
Malin, Michael C.	AZ St U
Mao, Ho-kwang	Carnegie Inst. of Wash.
Martin, Terry Z.	JPL
Matson, Dennis	JPL
Maxwell, Ted A.	Smithsonian
McCord, Thomas B.	U HI
McEwen, Alfred S.	USGS, Flagstaff
McFadden, Lucy-Ann	U CA, San Diego
McGill, George E.	U MA, Amherst
McKay, Christopher	NASA/ARC
McKinnon, William B.	Wash. U
Melosh, H. J.	U AZ
Metzger, Albert E.	JPL
Moore, Henry J.	USGS, Menlo Park
Mouginis-Mark, Peter J.	U HI

PG&G PROGRAM: SUPPORTED PROPOSALS IN FY 90

INVESTIGATOR

INSTITUTION

Murali, A.V.	LPI
Murray, Bruce C.	Cal Tech
Nash, Douglas B.	San Juan Res. Inst.
Nellis, William J.	LLNL
Nicholson, Philip D.	Cornell
Olson, Peter	Johns Hopkins
Orenberg, James B.	San Francisco St U
Ostro, Steven J.	JPL
Owen, Tobias C.	U HI
Paige, David A.	UCLA
Parmentier, E. M.	Brown
Patterson, Chris W.	Los Alamos Natl. Lab.
Peale, Stanton J.	U CA, Santa Barbara
Phillips, Roger J.	SMU
Pieters, Carle M.	Brown
Plescia, Jeffrey B.	JPL
Polek, Thomas E.	NASA/ARC
Pollack, James B.	NASA/ARC
Porco, Carolyn C.	U AZ
Richter, Frank M.	U Chicago
Sagan, Carl	Cornell
Salisbury, John W.	Johns Hopkins
Saunders, R. Stephen	JPL
Schaber, Gerald G.	USGS Flagstaff
Schmidt, Robert M.	Boeing
Schubert, Gerald S.	UCLA
Schultz, Peter H.	Brown
Scott, David H.	USGS Flagstaff
Sharpton, Virgil L.	LPI
Sheridan, Micahel F.	AZ St U
Shoemaker, Eugene M.	USGS Flagstaff
Singer, Robert B.	U AZ
Soderblom, Laurence A.	USGS Flagstaff
Solomon, Sean C.	M.I.T.
Spudis, Paul D.	USGS Flagstaff
Squyres, Steven W.	Cornell
Stevenson, David J.	Cal Tech
Stewart, Glen R.	U CO
Strom, Robert G.	U AZ
Tanaka, Kenneth L.	USGS Flagstaff
Thomas, Peter C.	Cornell
Thompson, Thomas W.	JPL
Tittemore, William C.	U AZ
Turcotte, Donald L.	Cornell
Tyler, G. Leonard	Stanford
Underwood, James R., Jr.	KS St U
Veverka, Joseph	Cornell

PG&G PROGRAM: SUPPORTED PROPOSALS IN FY 90

INVESTIGATOR

INSTITUTION

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Ward, William R.	JPL
Warren, Stephen G.	U WA
Watters, Thomas	Smithsonian
Weidenschilling, Stuart	PSI
Weissman, Paul R.	JPL
Wetherill, George W.	Carnegie Inst. of Wash
Whipple, Fred L.	Smithsonian
Williams, James G.	JPL
Wisdom, Jack	M.I.T.
Wu, Sherman	USGS Flagstaff
Yoder, Charles F.	JPL
Zimbelman, James	Smithsonian
Zisk, Stanley	U HI
Zuber, Maria T.	NASA GSFC

## PROPOSAL SUMMARY / ABSTRACT

### PRINCIPAL INVESTIGATOR

John B. Adams  
Dept. of Geological Sciences AJ-20  
University of Washington  
Seattle, WA 98195  
(206)543-6221

### CO-INVESTIGATORS

Milton O. Smith

### PROPOSAL TITLE

Spectral Reflectance of Planetary Surfaces

### ABSTRACT

a. Our overall research objective is to provide new information on the chemistry, mineralogy and geology of planetary surfaces using multispectral images and reflectance spectra in the visible and near-infrared wavelength region. The approach is to interpret the remotely sensed data in terms of laboratory reference spectra, and to use spectral mixing models to quantify mineral phase-abundances.

b. We worked with Ray Arvidson's group on two approaches to the intercomparison of Viking Lander, Viking Orbiter, telescopic and laboratory reflectivity spectra. We calibrated Viking multispectral images using available information on the instrument responses, and we derived photometric and atmospheric parameters. We also calibrated the data sets using a spectral mixing model. The two approaches were compared. They provide a basis for interpreting the surface composition of Mars at a wide range of spatial scales. We continued work with Paul Johnson on a semiempirical model for calculating binary mineral mixtures which vary in particle size and illumination geometry. Calculated mixtures are within laboratory experimental errors.

c. In the coming year we propose to investigate: 1) the effect of spatial scale on spectral mixing; and 2) the spectral mixing systematics of sets of telescopic spectra of Mars, the moon and asteroids.

d.

Johnson P.E., Singer R.B., Smith M.O., and Adams J.B. Quantitative determination of mineral abundances and particle sizes from reflectance spectra, J. Geophys. Res., in press.

Adams J.B., Smith M.O., Guinness E.A., and Arvidson R. E.1988. Geologic units on Mars: Spectral and textural mixing evidence from Viking Orbiter, J. Geophys. Res., in preparation.

Arvidson R.E., Dale-Bannister M.A., Guinness E.A., Adams J.B., Smith M.O., Christensen P.R., and Singer R.1988. Nature and distribution of surficial deposits in Chryse Planitia and vicinity, Mars, J. Geophys. Res., 94.B2, 1573-1587.

Smith M.O. and Adams J.B., Isolation of compositional variance from Viking Lander multispectral images, (abs.) Lunar and Planetary Science Conference XX, March, 1989.

Type abstract single-spaced, paragraphs numbered:

- (a) brief statement of the overall objectives and justification of the work;
- (b) brief statement of accomplishments of prior year, or "new proposal";
- (c) brief listing of what will be done this year, how, and why;
- (d) one or two of recent publications relevant to proposed work.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:

Thomas J. Ahrens  
Seismological Laboratory  
California Institute of Technology  
Pasadena, CA 91125 818/356-6906

CO-INVESTIGATOR(S):

TITLE:

Impact Cratering Calculations

ABSTRACT:

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### a. Objectives:

To describe and understand the physics of impact cratering, both normal and oblique, on planetary surfaces composed of solid silicates, ices, and their regoliths, as well as impacts into planetary atmospheres and proto-atmospheres and into the ocean. On a larger scale we expect to constrain impact conditions for partial and complete loss of atmospheres as well as whole planet, devolatilization melting and/or disruption. This includes determining energy partitioning, ejecta distributions (with regard to size, velocity, energy content, and sorting), and condensation physics of impact produced vapor as well as the impact production of aerosols from the liquid and solid state.

### b. Accomplishments:

1) Developed a computer model which can explicitly describe impact onto a self gravitating exponential planetary atmosphere and the resulting solid ejecta-atmosphere interaction. Calculated impact-induced flow from a large (10 km-diameter, 20 km/sec) bolide onto an earth-sized planet with an exponential atmosphere. We have determined that some 6% of bolide energy couples to the atmosphere. This is close to the value, 5.3%, inferred from similarity variable analysis of the hemispherical shock wave in the air.

2) We have begun test calculations using a new smooth particle hydrodynamic code capable of studying atmospheric loss and total planet melting and disruption upon impact of two like-sized self gravitating planetary-sized objects.

3) Determined, via finite-difference calculations, the effect of planetary crustal strength and planetary gravity and/or impactor energy on the transition between cratering controlled by strength, versus, that controlled by gravity. Quantitatively demonstrated how planetary gravity, strength and crater scale gives rise to gravity-induced crater rebound. We have demonstrated that the crater diameter for transition from simple to complex craters varies as  $g^{-1}$  for silicate terrestrial planets and varies from  $g^{-0.3}$  to  $g^{-1.0}$  for icy satellites depending on the effective viscosity of the satellite.



4) In analyzing the effect of impact of a large, Cretaceous-Tertiary sized-, impactor on the earth, we have examined the experimental data for impact induced fine ejecta in the aerosol ( $<1\mu\text{m}$ ) range and find that only  $10^{-5}$  of the  $3-20 \times 10^{18}$  g of ejecta from a K/T impactor is in fines  $< 1 \mu\text{m}$ . This is a factor of  $10^2$  to  $10^3$  less than previous estimates of optically dense material lofted into the stratosphere.

### c. Proposed Program

1) Conduct atmospheric impact cratering calculations to determine the mass of atmosphere ejected and lost from a planet (with exponential atmospheres) upon impact of different density, diameter, and velocity bolides.

2) Complete a study of the effect of gravity, velocity target strength, and projectile dimensions on the depth of excavation and crater shape upon impact of large bolides on planetary surfaces. The major effect we expect to study is the scaling appropriate for high velocity impacts where shock-induced vaporization accounts for a major fraction of the crater volume.

3) We propose to study very large body impacts with our self-gravitating smooth particle hydrodynamic code. We expect to examine partitioning of energy and momentum for different velocity, impact angle and equation of state, as well as the degree of planetary melting and devolatilization.

### d. References

1. Ahrens, T. J., O'Keefe, J. D., and Lange, M. A., 1989, Formation of atmospheres during accretion of the terrestrial planets, *Planet and Satellite Atmospheres: Origin and Evolution*, ed. S. Atreya and J. Pollack, U. Ariz. Press, Tucson, AZ., in press.
2. Lange, M. A. and Ahrens, T. J., 1989, Atmospheric blow-off during accretion of the terrestrial planetary atmospheres, submitted to *Icarus*.
3. O'Keefe, J. D. and Ahrens, T. J., 1989, Impact produced condensate and droplet size distributions, submitted to *Icarus*.
4. O'Keefe, J. D. and Ahrens, T. J., 1989, Impact production of  $\text{CO}_2$  by the K-T extinction bolide and the sudden heating of the Earth, *Nature*, 338, 247-249.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:

Thomas J. Ahrens  
Seismological Laboratory  
California Institute of Technology  
Pasadena, CA 91125 818/356-6906

CO-INVESTIGATOR(S):

TITLE:

Impact and Collisional Processes in  
the Solar System

ABSTRACT:

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**a. Objectives:**

We are carrying out experimental research on mechanical and thermodynamic aspects of shock and impact cratering and accretionary processes in solid planets, and their atmospheres and satellites. Experiments are being conducted to understand impact induced melting and vaporization of minerals on the terrestrial planets, their satellites and the icy satellites of the outer solar system. Recent theories of the impact origin of the moon and impact devolatilization of Mercury need to be tested with these data.

We measure the shock pressure, and hence, infer corresponding impact velocities of infalling planetesimals during planetary accretion which are required to induce melting of iron, sulfides, and oxides which precedes planetary core formation. We are studying the release of volatiles by impact on water-, carbon dioxide-, sulfur-bearing minerals, and hydrocarbons in the laboratory because this process is believed to underlie the accretion of planetary atmospheres. Studies of noble gas devolatilization are conducted to constrain theories of atmospheric evolution. We combine experimental data on shock induced melting and vaporization and theories of planetary atmospheric growth to understand the chemistry of interaction of hot proto-planetary surfaces with proto-atmospheres. To understand impact production of melt and vapor from silicates and formation of magma oceans on the earth, Moon, and Venus, we are studying shock temperatures in the minerals of planetary crusts and mantles. We are conducting shock loading experiments on rocks in order to understand and be able to describe their mechanical response which gives rise to the observed negative Bouguer gravity anomalies observed over impact craters on the earth and moon and seismic velocity deficits beneath impact and explosion craters.

**b. Accomplishments:**

1) We have carried out the first experimental studies of the solubility of Ar in carbon glass in order to both understand how noble gases become dissolved in carbonaceous material in the solar nebulae and to provide sample material to conduct impact devolatilization experiments.

2) New gas recovery shock devolatilization experiments were conducted on serpentine, serpentine enriched in D, and Murchison carbonaceous chondrite. All three materials demonstrate that incipient to complete loss of water occurs upon subjecting these materials to shock pressures in the range of 100 to 300 kbar. This is in approximate agreement with previous experiments in which only the solid phase was recovered and analyzed. Marked depletion of the evolved water and hydrogen in deuterium by as much as  $\Delta\delta D = -100\text{‰}$  was discovered. We attribute the preferential partitioning of deuterium into the solid phase as a result of a kinetic effect in the reaction of iron with water during the shock devolatilization process. If this process occurs during planetary accretion, it leads to a new scenario in which the early deuterium depleted atmosphere is lost by Jeans' loss or by hydrodynamic escape and a later forming atmosphere has a greater D/H ratio. We propose that such a scenario might have occurred on Mars and Venus.

3) New Hugoniot equation of state data for brucite  $\text{Mg}(\text{OH})_2$  to 60 GPa demonstrate that like  $\text{MgO}$ , this mineral does not undergo a phase change over this pressure range. Moreover, these shock data when analyzed in terms of possible breakdown to  $\text{MgO} + \text{H}_2\text{O}$  may permit determination of whether water remains associated in the solid state at high pressures in planetary mantles. The release isentrope data for brucite shows strong evidence for devolatilization upon pressure release and needs to be analyzed in detail and compared to previous shock recovery data.

4. We have nearly completed construction of VISAR (Velocity Interferometer System for a Reflecting Surface) which will be used to conduct a rigorous program of study of the impact vaporization of rocks. Virtually no experimental data on the conditions for impact volatilization of rocks are available, yet the most recent theories of the origin of the moon and the devolatilization of Mercury appeal to this, at present, poorly understood process.

5) We have conducted a series of impact experiments on blocks of San Marcos gabbro and Bedford limestone which demonstrate 30 and 50% crack-induced reduction in P-wave velocity due to 900 MPa shock pressures. One-dimensional spall experiments to relate dynamic tensile stress to the resulting velocity deficit and crack density are also being conducted on these rocks.

### c. Proposed Program

We propose to:

1) continue our initial study of the uptake of Ar and other noble gases in carbon and hydrocarbons and study their devolatilization both via shock and via annealing. We expect to start dissolving noble gases in silicates and also study the devolatilization behavior of other minerals. In collaboration with Professor Frank Podosek and Dr. Thomas Bernatowicz, we expect to study the impact devolatilization of noble gases from primitive meteorites.

2) search for and analyze the solid phases ( $\text{MgSiO}_3$ ,  $\text{Mg}_2\text{SiO}_4$ ,  $\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$ ) remaining upon partial devolatilization of serpentine and Murchison meteorites. The serpentine is predicted to be enriched in D/H. We propose to also study the gaseous species produced upon shocking Murchison meteorite and elucidate the chemistry and isotopic variations which appear to occur in the gas phase.

3) conduct further analysis of the equation of state of brucite and construct a model which describes the release isentropes in terms of the equation of state and thermodynamic properties of  $\text{MgO}$  and  $\text{H}_2\text{O}$ .

4) conduct further experiments on the cracking and hence density and seismic velocity deficit induced by shock waves in both hemispherical and planar geometry in dry and wet rocks. We expect to examine the data prescribing the regions of velocity deficits

beneath such craters as the Ries and Meteor crater and determine what constraints these anomalies can place on the impact process.

5) Conduct further experimental impact studies of rocks and determine the effects of velocity and size scaling on the production of aerosol-sized ejecta.

**d. References**

1. Lange, M. A. and Ahrens, T. J., 1987, Impact experiments in low temperature ice, *Icarus*, **69**, p. 506-518.
2. Tyburczy, J. A. and Ahrens, T. J., 1988, Dehydration kinetics of shocked serpentine, *Proceedings of the 18th Lunar and Planetary Science Conference*, Cambridge Univ. Press, p. 435-442.
3. Schmitt, D. R. and Ahrens, T. J., 1988, Shock temperatures in silica glass, *J. Geophys. Res.*, in press.
4. Tyburczy, J. A., Krishnamurthy, R. V., Epstein, S., and Ahrens, T. J., 1989, Impact induced devolatilization and hydrogen isotopic fractionation of serpentine: Implications for planetary accretion, submitted, *Earth Planet. Sci. Lett.*
5. Tan, H. and Ahrens, T. J., 1989, Shock-induced polymorphic transition in quartz, carbon, and boron nitride, *J. Appl. Phys.*

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James R. Arnold  
California Space Institute, A-021  
Scripps Institution of Oceanography  
University of California, San Diego  
La Jolla, CA 92093  
(619)534-2908

ASSOCIATE INVESTIGATORS: K. Nishiizumi  
E. M. Shoemaker

PROPOSAL TITLE: Age and Erosional History of Meteorite Craters  
Using Cosmogenic Nuclides

## ABSTRACT:

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(a) We propose to measure the age of the five known meteorite impact craters in Australia, by a combination of measurements of cosmogenic nuclides in meteorite specimens and in samples of quartz-bearing rocks exposed by the impact. Samples of both sorts have been collected for this work by E. and C. Shoemaker; further collections are planned. For older craters the terrestrial quartz data will measure primarily erosion rates in crater and ejecta materials; for younger ones crater age determination may be possible. The most important radionuclides are  $^{14}\text{C}$  (to be measured at Arizona),  $^{10}\text{Be}$  and  $^{26}\text{Al}$  (to be measured at Pennsylvania). These measurements can provide estimates of the impact rates on earth of iron and stony-iron meteoroids in the 1-50 meter size range, and of the rate of disappearance of impact craters in arid regions. As part of this study we will continue our dating and erosion studies of Meteor Crater, Arizona.

(b) New Proposal

(c) With our AMS colleagues we will measure  $^{14}\text{C}$ ,  $^{10}\text{Be}$ , and  $^{26}\text{Al}$  in terrestrial quartz collected at the five Australian craters and at Meteor Crater, Arizona. We will also measure these radionuclides in meteoritic metal collected at these craters. Some further sampling will be carried out in Australia.

(d) Nishiizumi et al (1989b)  
Nishiizumi et al (1989c)

## PROPOSAL SUMMARY

### PRINCIPAL INVESTIGATOR:

Raymond E. Arvidson, Professor  
McDonnell Center for the Space Sciences  
Department of Earth and Planetary Sciences  
Washington University  
St. Louis, MO 63130  
Telephone: 314-889-5609

### CO-INVESTIGATOR:

Edward A. Guinness, Senior Research Scientist

### SCIENTIFIC COLLABORATORS:

Raymond Jurgens  
Anne Kahle  
Ralph Kahn  
Daniel McCleese  
R. Stephen Saunders  
Jakob Van Zyl  
Richard Zurek  
Jet Propulsion Laboratory

Ronald Greeley  
Arizona State University  
  
James Pollack  
NASA Ames Research Center  
  
Richard Simpson  
Stanford University  
  
Robert Singer  
University of Arizona

### TITLE: ANALYSIS OF REMOTE SENSING DATA FOR THE SURFACES OF THE TERRESTRIAL PLANETS

- A. Objectives: Acquisition and analysis of airborne AVIRIS, TIMS, quad-pol radar, and ground data over GRSFE test sites to test models for-extraction of surface property information. Data and documentation to be archived for planetary community use. Geology of Venus, including rates of resurfacing by both endogenic and exogenic processes. Surficial geology of Mars using visible, thermal, microwave wavelengths, stressing genetic relationships between local bedrock and sedimentary cover.
- B. Accomplishments: (1) Detailed planning for joint EL/EE airborne and ground GRSFE deployment using AVIRIS, TIMS, quad-pol radar systems; (2) Used Seasat data to simulate geological information in Venera and Magellan images; (3) Re-evaluated evidence for clustering of craters on Venus and whether a production population exists; (4) Generated review articles (with H. Moore, J. Gooding) on Viking Lander results, on Planetary Geology, and on Martian weathering (with Gooding et al.); (5) Analyzed impact crater population on Mars south pole; (6) Pursued use of visible, thermal, microwave to characterize and map Mars surficial materials exposed in Oxia and surroundings; (7) Photogeological analyses of Goldstone Venus images.
- C. Proposed Work in 1990: (1) Reduce and analyze airborne and ground remote sensing data over GRSFE test sites in Mojave desert. Assembly of archive of reduced data and documentation. With PDS help, publish set of 10 CD-ROMs of GRSFE data for community use; (2) Explore separation of reflectivity from roughness, and geological ramifications of results using Goldstone Venus data; (3) Implement visible through thermal IR radiative transfer models for extraction of surface information from Viking data; (4) Characterize Martian surface materials in northern equatorial region using multi-angle Viking images, IRTM, and radar data; (5) Studies of aeolian geology of Venus with Greeley.
- D. Publications: See Appendix II and Table of Contents.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Victor R. Baker  
(Name, Address, Department of Geosciences, University of  
Telephone Number) Arizona, Tucson, AZ 85721 (602) 621-6003

Co-INVESTIGATORS: \_\_\_\_\_  
(Name Only) \_\_\_\_\_

PROPOSAL TITLE: Planetary Geomorphology

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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- A. Determine the origins, ages, and hydroclimatic significance for various channels, valleys, and related hydrogeomorphic features on Mars through photointerpretation of orbital imagery, comparison to terrestrial analogs, and theoretical studies of fluvial/hillslope mechanics and hydrologic processes.
- B. 1) Applied new hydraulic flow-modeling procedures to the calculation of cataclysmic flood parameters for the Channeled Scabland and for Martian outflow channels. 2) Improved the understanding of sapping origins for some Martian valley networks by studies of Hawaiian volcano valleys. 3) Developed a preliminary hydrothermal model to explain the origin of most Martian valleys. 4) Documented the anomalous character of valleys on Alba Patera in relation to the general timing and inferred processes of valley formation on Mars.
- C. Develop new theoretical criteria for relating Mars channel-erosional evidence to causative flow process mechanics. Use appropriate field data from Channeled Scabland to test model predictions. Adapt to Martian parameters various computer models used for simulating terrestrial hydrothermal systems. Compare predictions of the hydrothermal hypothesis to atmospheric models of paleoclimatic change on Mars. Continue to use combined geomorphological mapping, morphometric analysis, photointerpretation, and theoretical analysis of advance understanding of Mars hydrogeomorphology, and extend this experience to megageomorphological comparison of Earth, Mars, and Venus.
- D. Baker, V.R., 1988, Geological fluvial geomorphology: Geological Society of America Bulletin, v. 100, p. 1157-1167.  
Baker, V.R., 1988, The channels of Mars, in The NASA Mars Conference: American Astronaut. Soc., v. 71, p. 75-90.

## PROPOSAL SUMMARY

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CO-INVESTIGATOR: Joy A. Crisp

TITLE: QUANTITATIVE STUDIES IN PLANETARY VOLCANISM

OBJECTIVES: 1) To develop quantitative methods for assessing the relative influence of topographic and rheological controls on the emplacement of planetary lava flows and apply the results to lava flows on selected volcanoes on Mars, 2) To determine whether the composition of lobate and sheet flows on Io is sulfur or silicate, 3) To develop new energy balances for explosive eruption columns on Mars that incorporate Stefan-Boltzmann radiation and particle losses and explore selected morphological features in conjectured ash deposits, and 4) To develop quantitative constraints on the source of magma supply from lava flow and flow fields on Mars.

PROGRESS : Corresponding to the above objectives, recent progress has been 1) Completed modeling of flow emplacement from Puu Oo 1983-1984 eruption, identified model shortcomings, and scaled model for Mars gravity, 2) Performed preliminary qualitative and quantitative analyses of arguments in favor and against sulfur flows on Io, 3) Reformulated the original equations for buoyant plumes and obtained energy integrals, and 4) Completed feasibility study at Alba Patera on the use of lava flow data to constrain sources of magma supply.

PROPOSED WORK: Corresponding to the above objectives, 1) Incorporate recent fluid mechanics developments into existing models for lava emplacement and compare predictions with terrestrial and planetary data, 2) Use new models and morphologic information to establish composition of lava flows on Io, 3) Obtain new energy balances for volcanic plumes and re-assess existing thoughts on explosive volcanism on Mars, including mantled deposits with hummocks and ridges, and 4) Investigate major magmatic supply and flow emplacement factors that could produce systematic trends in surface expression of lava flow fields on Mars.

SUMMARY BIBLIOGRAPHY : Baloga, S., (1987), Lava flows as kinematic waves, JGR 92, 9271-9279; Crisp, J. and S. Baloga, (1989), Lava flows with two thermal components, submitted to JGR, March 1989; Baloga, S. and J.Crisp, (1988), Leveed lava flows on Mars, Icarus, in revision; Baloga, S. and D. Pieri, (1986), Time-dependent profiles of lava flows, JGR, 91, 9543-9552



## PROPOSAL SUMMARY

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4800 Oak Grove Drive  
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CO-INVESTIGATORS: None

TITLE: Planetary Tectonics

### ABSTRACT

A. The broad objective is to better understand the mechanical behavior, structure, and history of the crusts and upper mantles of the solid planets and satellites.

B. During the past six months we have: (i) reconciled differences between existing stress models for Tharsis and generated high resolution plots for use in comparing mapped tectonic features with theoretical predictions; (ii) continued the investigation of mechanical/petrological constraints on the evolution of Tharsis, with one paper published and another manuscript submitted for publication; (iii) completed the study of early thermal gradients on Europa using lithospheric strength envelopes and observations of extensional tectonic features, with a manuscript submitted for publication.

C. I propose to do the following: (i) continue the investigation of the effects of mantle dynamics on surface stress fields in planetary lithospheres, and perform regional studies of the state of stress in selected areas on Venus at moderate resolution in order to refine regional models of the lithosphere and upper mantle of Venus; (ii) continue the work underway using stress predictions, petrological constraints, and tectonic observations to test various models for the thermal and tectonic history of the Tharsis region of Mars, and develop a general thermomechanical modelling framework for further extending these studies; and (iii) investigate tectonic deformation processes and subsurface structure on Io using realistic rheological assumptions.

#### D. Selected References:

- Banerdt, W. B., and M. P. Golombek, Long wavelength stress models for Mars: New and improved, *Lunar Planet. Sci. XX*, 40-41, 1989.
- Phillips, R. J., N. H. Sleep, and W. B. Banerdt, Permanent uplift in magmatic systems with application to the Tharsis region of Mars, *J. Geophys. Res.* in review, 1989.
- Finnerty, A. A., R. J. Phillips, and W. B. Banerdt, Igneous processes and closed system evolution of the Tharsis region of Mars, *J. Geophys. Res.*, **93**, 10225-10235, 1988.
- Golombek, M. P., and W. B. Banerdt, Constraints on the subsurface structure of Europa, *Icarus*, in review, 1989.
- Banerdt, W. B., Global dynamic stress modelling on Venus (abs.), *Lunar Planet. Sci. XIX*, 25-26, 1988.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Jeffrey F. Bell  
(Name, Address, Planetary Geosciences Div., Hawaii Inst. of Geophys.  
Telephone Number) Univ. of Hawaii, 2525 Correa Rd., Honolulu, HI 96822  
(808) 948-6488

Co-INVESTIGATORS:  
(Name Only) ---

PROPOSAL TITLE: Spectral Studies of Possible Asteroidal Materials  
NAGW 712

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. The objective of the proposed work is to improve our understanding of the surface mineralogy of asteroids, and to link the vast existing body of meteorite geochemical data with specific astronomical objects which may be targets of future NASA missions. The methodology to be employed is: 1) prepare simulated asteroid regolith material by pulverizing meteorite samples or constructing artificial mineral mixtures corresponding to hypothetical asteroid compositions, 2) obtain IR (0.3-5.0 micron) reflection spectra of the simulated regolith, 3) analyze the lab spectra for systematic changes with composition, 4) use the knowledge obtained in the lab to analyze asteroid spectra obtained telescopically and develop mineralogical interpretations of the surfaces of selected objects, and 5) integrate the mineralogical information with other astronomical data, orbital dynamics, and meteorite studies to reconstruct the condensational, thermal, and collisional history of the asteroids and their parent planetesimals.

b. Completed chapter for *Asteroids II* volume; published results of asteroid family study; obtained lab spectra of unique chondrite ALHA 85085; investigated use of scattering theory to determine asteroid composition,

c. Obtain laboratory spectra of possible outer solar system organic darkening materials; obtain spectra of graphite-magnetite matrix material, FeS, and shocked veins in chondrites; investigate application of scattering theory to asteroid regoliths; complete manuscript on pallasite origins.

d. J. F. Bell and K. Keil, Spectral alteration effects in chondritic gas-rich breccias: Implications for S-class and Q-class asteroids. *Proc. Lunar Planet. Sci. Conf. 18th*, Cambridge Univ. Press, 573-580; J. F. Bell, A probable asteroidal parent body for the CV or CO chondrites. *Meteoritics* 23, 256-257.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: J.W. Boring  
(Name, Address, Department of Nuclear Engineering and  
Telephone Number) Engineering Physics, University of Va.  
Charlottesville, VA 22901 (804-924-3213)

Co-INVESTIGATORS: R.E. Johnson  
(Name Only) "Laboratory Reflectance Spectra of Irradiated  
Ices: Applications to Europa"

PROPOSAL TITLE:

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

### Abstract:

a) A great deal of information has been obtained concerning the nature of the surfaces of bodies in the solar system by studying their reflectance spectra, either by ground based observations or by spacecraft measurements. There is, however, a large need for suitable laboratory measurements that will allow one to unambiguously interpret the astronomical data in terms of the actual composition of the surfaces. There is a particular need for laboratory studies of the effects of plasma ion bombardment of the icy materials that comprise the surfaces of many of the satellites and rings of the outer planets. This proposal addresses this need and is concerned with a particular planetary body - Europa. We are concerned with the reflectance of  $H_2O$  (both pure and in mixtures) in the visible and UV and the changes in this reflectance effected by bombardment of the surface by ions typical of those present in Jupiter's magnetosphere. The results of these measurements will then be used to interpret the available reflectance data on Europa itself and provide a framework for future studies of this and similar surfaces in the solar system.

b) There has been only one month from the time of notification of funding for the present year and the preparation of this proposal. During this time we have assembled the new spectroscopic system and studied briefly the reflectance of  $H_2O$  in the wavelength range  $0.22 - 0.55 \mu m$  as a function of the fluence of bombardment by  $SO_2^+$  ions.

c) Films of  $H_2O$  and mixtures including  $SO_2$ ,  $NH_3$  and  $CO$  are deposited onto a metallic substrate. The temperature of deposition is an important parameter governing the surface topography of the ice film. The reflectance of the surface in the wavelength range  $0.22 - 0.8 \mu m$  of light from a high pressure Xe arc source will be studied as a function of the irradiation of the sample with various ions such as  $S^+$ ,  $H^+$  and  $O^+$  that are present in the Jovian magnetosphere. The growth of the film, the ion bombardment and the reflectance studies will all be performed in a vacuum system that has a base pressure of  $10^{-9}$  Torr. The specific aim of these studies is to assess the effects of plasma bombardment on the reflectance spectra of Europa and similar bodies and identify the chemical species responsible for the changes observed in the spectra.

d) Relevant publications: "Measurements of Reflectance Spectra of Ion-bombarded Ice and Application to Surfaces in the Outer Solar System", D.J. O'Shaughnessy, J.W. Boring and R.E. Johnson, *Nature* **333**, 240-241 (1988).  
"Voyager Images of Europa: Plasma Bombardment", R.E. Johnson, M. Nelson, T.B. McCord and J. Gradie, *Icarus* **75** (1988), 423-436.

## Proposal Summary

*Principal Investigator:* Alan P. Boss  
Department of Terrestrial Magnetism  
Carnegie Institution of Washington  
5241 Broad Branch Road N.W.  
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(202)686-4402

*Proposal Title:* Three Dimensional Evolution of the Solar Nebula

### Abstract

(a) *Objective:* Numerical calculation of the formation and early evolution of the solar nebula, including the most important physical processes: three dimensional (3D) hydrodynamics, self-gravitation, radiative transfer, and complete gas thermodynamics. The models seek to improve our understanding of the dynamics and thermodynamics of the solar nebula, and hence our understanding of basic physical processes and conditions of crucial importance for planetary formation.

(b) *Progress:* (1) A major survey of parameter space for 3D models of solar nebula formation has (a) shown the importance of gravitational torques for rapid angular momentum transport in the nebula, (b) demonstrated the possibility of high temperatures ( $\sim 1500$  K) in the inner nebula, and (c) shown the apparent impossibility of obtaining high enough surface densities to explain the rapid formation of Jupiter and the giant planets, even for models starting from alternative initial conditions. (2) Study of protostellar hiccups with 1D and 3D models has shown that the hiccup phenomenon is suppressed in very rapidly rotating protostars, but hiccups may eject energetic streams of gas into the innermost nebula in more slowly rotating models. (3) The radiative transfer solution method has been successfully extended to include the 3D Eddington approximation at very high optical depths. (4) Second order accurate hydrodynamical schemes have been tested on a variety of 1D test problems.

(c) *Proposed work:* The primary goal is to complete the testing of second order accurate hydrodynamical schemes on 1D and 3D test problems, and to include the improved coding in the next set of production models. Other important improvements such as use of the 3D Eddington approximation and higher spatial resolution are anticipated, particularly if a faster processor is obtained. While the emphasis is thus on code development in the second year, a few new solar nebula models may be completed with intermediate or final versions of the code.

(d) *Summary bibliography* (3/88 - 2/89, first year, PI only): 7 papers published or submitted, 7 abstracts, 15 oral presentations. Two representative publications:

A. P. Boss, High Temperatures in the Early Solar Nebula, *Science*, **241**, 565-567, 1988.

A. P. Boss, Evolution of the Solar Nebula I. Nonaxisymmetric Structure During Nebula Formation, *Astrophys. J.*, submitted, 1988.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Robert H. Brown  
Jet Propulsion Laboratory  
M.S. 183-501  
4800 Oak Grove Dr.  
Pasadena, Ca. 91109

CO-INVESTIGATORS: Dennis L. Matson

TITLE: Testing solid-state greenhouse models using thermal IR  
eclipse observations of icy satellites.

### ABSTRACT:

a) OBJECTIVES: To use existing observations of eclipses of the Galilean satellites in the thermal infrared to test and refine the solid-state greenhouse model. To advance understanding of surface and near-surface temperature distributions of icy satellites and to provide important input to thermal-history calculations for icy satellites. Our main objective is to modify and use our existing solid-state greenhouse models to interpret observations of the full-disk thermal flux during eclipse immersions and emersions of Europa and Ganymede. This will enable us to obtain estimates of the penetration scale length for sunlight on icy satellites and thus to more accurately model the surface and near-surface temperature distributions of satellites such as Europa and Enceladus. This is essential for determining upper boundary-layer temperatures of icy satellites. Preliminary models constructed by us have shown that recognition of and understanding the nature and scope of the solid-state greenhouse effect is quite important to understanding icy-satellite thermal histories and their geological evolution.

b) PROGRESS: Preliminary analysis of eclipse data on Europa shows strong evidence for a solid-state greenhouse; subsurface temperature enhancements of  $-40$ - $50^{\circ}\text{K}$  are suggested. Our models have been generalized to include variable thermal parameters, and we have incorporated that generalized thermal modeling code into the most accurate and detailed numerical model of Jovian satellite eclipses produced to date.

c) PROPOSED WORK: We propose to continue to interpret, using solid-state greenhouse models, thermal-infrared eclipse flux curves of Ganymede and Europa. We will be further improving our eclipse modeling code to include the effects of the Jovian penumbra on satellite eclipses and will investigate ways to include vapor and heat transport to study how an icy regolith responds to the solid-state greenhouse effect. We will also study the effect on profiles of solar energy deposition with depth from differing regolith parameters (porosity, albedo, grain size etc.).

d) SUMMARY BIBLIOGRAPHY: Brown, R. H. and D. L. Matson (1987), "Thermal effects of insolation propagation into the regoliths of airless bodies", *Icarus* 72, 84-94; D. L. Matson and R. H. Brown (1987), "Solid-State greenhouses and their implications for icy satellites", *Icarus* 77, 67-81.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Joseph A. Burns  
**(Name, Address,** Center for Radiophysics and Space Research  
**Telephone Number)** Cornell Univ., Ithaca, NY 14853. (607) 255-7186/6909

**Co-INVESTIGATORS:** None  
**(Name Only)** \_\_\_\_\_

**PROPOSAL TITLE:** Physical Processes in Planetary Rings

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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a.) We wish to understand the processes that produce the elegant ring structures that encircle planets. Our research emphasizes narrow isolated rings and, especially, faint rings comprised of dust grains; in these cases somewhat different physics comes into play than in the dense main rings. An appreciation of the causative mechanisms that act in planetary rings should help us comprehend the processes that occurred in the solar nebula and the circumplanetary disks out of which planets and satellites, respectively, grew.

b.) Full proposal for three year renewal.

c.) We will complete our analysis of the images of Saturn's isolated F ring and our dynamical simulation of this narrow and shepherded ring; the latter dynamics will also be applied to other narrow rings and gaps, e.g., the width variation of the Keeler Gap. We will prepare for publication our completed research about the physics of circumplanetary dust grains (electric charging, orbital evolution and passage through Lorentz resonances). We will investigate various ring problems involving electromagnetic forces on small grains (including Saturn's spokes), the origin and structure of the E ring, and charged particle absorption signatures of satellites and dust clouds. We will also consider the origin and evolution of faint rings, especially the Uranian dust ring, and the capability of circumplanetary grains to account for the observed asymmetrical coating of various satellites.

d.) J. A. Burns and L. Schaffer 1989. Orbital evolution of circumplanetary dust by resonant charge variations. *Nature* 337, 340-343.

J. N. Cuzzi and J. A. Burns 1988. Charged particle depletion surrounding Saturn's F ring: Evidence for a moonlet belt? *Icarus* 74, 284-324.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Roger G. Burns  
(Name, Address, Bldg. 54-816, M.I.T., Cambridge, MA 02139  
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Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE: Surfaces: Electronic Spectra of Materials Simulating Planetary  
Oxidation Products on Mars and Venus

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objectives: Iron-bearing minerals on terrestrial planets are vulnerable to pervasive oxidative weathering, during which distinctive Fe(III) phases are produced. Such ferric-bearing assemblages, once identified, may reveal parent rock-types and surface weathering processes on the planet. Since the Fe(II) and Fe(III) minerals are amenable to a variety of spectroscopic techniques, reaction pathways from primary Fe(II) silicates and sulfides to secondary Fe(III) phases may be deduced from measurements of visible - near infrared and Mossbauer spectra. Spectral features of experimentally degraded minerals may also enable oxidative weathering products to be identified in remote-sensed reflectance spectral profiles of planetary surfaces.

(b) Progress: A model for chemical weathering on Mars has been proposed by us in which near-surface oxidation of FeS minerals has produced acidic groundwater that altered primary Fe-Mg silicates in host komatiitic basalts. Reflectance spectral measurements of sulfuric acid-degraded olivines have demonstrated that diagnostic Fe<sup>2+</sup> crystal field bands become obscured by poorly crystalline goethite and jarosite phases identified by Mossbauer spectroscopy. Similar Fe<sup>3+</sup> phases were identified in the martian meteorites ALHA 77005 and Nakhla.

(c) Proposed Research: Oxidative weathering processes on Venus and Mars are being assessed from x-ray diffraction, electron microscope and microprobe, and visible - near infrared and Mossbauer spectral measurements of pyroxenes and olivines heated in CO<sub>2</sub>-dominated atmospheres and reacted with H<sub>2</sub>SO<sub>4</sub>. Spectral features are to be measured for Fe<sup>3+</sup>-O<sup>2-</sup>-bearing clay silicates (Mars), and biotite micas and calcic amphiboles (Venus) produced by heating Fe<sup>2+</sup>-OH<sup>-</sup>-bearing minerals in CO<sub>2</sub>-dominated atmospheres.

(d) Recent Publications: See published papers and abstracts by R.G.Burns, D.S.Fisher, K.S.Bartels, and T.C.Solberg in: *Proc. 19th LPSC*, 313 (1989); *Mineral. Mag.*, 53, 123 (1989); *Lunar Planet. Sci.*, XX, 44, 129 and 299 (1989); *EOS*, 69, 503 (1988); *MEVTV/LPI Tech. Rept. 88-05*, 34 (1988).

## PROPOSAL SUMMARY

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CO-INVESTIGATORS:

TITLE: Albedo Patterns of the Saturnian Satellites

### ABSTRACT

A. OBJECTIVE: The objective of this task is to quantify and explain the albedo and color variegations on the five inner medium-sized Saturnian satellites. We will investigate the interaction of the E-ring with their surfaces and other exogenic processes as a possible explanation for some of the albedo markings. A second goal is to develop general software to create albedo and color maps of planetary surfaces.

B. PROGRESS: (1) Completed color maps of the five Saturnian satellites: Enceladus, Mimas, Tethys, Dione, and Rhea. (2) Compiled all existing photometric observations of Ganymede and Callisto, including our own Voyager imaging measurements, to create accurate phase curves of these 2 satellites. (3) Made detailed comparison of albedo and color maps with geologic maps. (4) Improved our mapping software.

C. PROPOSED WORK: (1) Complete our analysis of processes, both exogenic and endogenic, which cause the albedo and color markings of the satellites. (2) Derive fundamental scattering properties of Ganymede and Callisto from our phase curves. (3) Make improvements to our computer programs, based on recent theoretical work.

D. SUMMARY BIBLIOGRAPHY:

- Buratti, B., et al., (1988) Applied Optics 27, 161-165.  
Buratti, B.J., (1988), Icarus, 75, 113-126.  
Buratti, B.J. and Golombek, M. (1988), Icarus 75, 437-151.  
Buratti, B.J., et al. (1988), Nature 333, 148.  
Lane, et al., (1988), Submitted to Icarus.  
Buratti, B., et al. (1988), Abstract 5.11 of Uranus Colloquium, June 28-July 1, 1988.  
Buratti, B., et al. (1988), B.A.A.S. 20, 855.  
Buratti, B., et al. (1989), submitted to Icarus.  
Buratti, B., et al. (1989), submitted to Icarus.



## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Donald B. Campbell  
(Name, Address, Space Sciences Building  
Telephone Number) Cornell University  
Ithaca, NY 14853 (607) 255-9580

Co-INVESTIGATORS: \_\_\_\_\_  
(Name Only) \_\_\_\_\_

PROPOSAL TITLE: Analysis of Radar Observations of Venus and  
The Moon

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) Several small studies of Venus and the moon are being proposed basically continuing and building on the current work. Current and soon to be acquired radar data sets for Venus and the moon will be used for: 1) a general description of the surface of Venus in the southern hemisphere area covered by the new Arecibo data; 2) a study of crater frequencies and distributions on Venus; 3) studies of volcanic flows and other features in Venus utilizing the polarization properties of the reflected signal and a comparison with equivalent results from terrestrial flows obtained with the JPL aircraft SAR system; 4) studies of the scattering mechanism associated with lunar impact craters, volcanic flows, etc. by means of high resolution radar imagery and polarization measurements.

b) Work over the past year has concentrated on the production and analysis of a new set of Arecibo radar images of Venus. Analysis work has concentrated on an area of approximately  $30 \cdot 10^6 \text{ km}^2$  at low northern latitudes which includes some overlap with the Venera 15/16 data. A general description has been made of the terrain plus an initial effort to identify impact craters and study their distribution in relation to the terrain units. Preparations are underway for a detailed study during the summer of the polarization properties of the reflected signal from volcanic flows and 'dark halo' areas and a comparison of the results with similar areas obtained for the earth.

c) We anticipate making progress in all the studies outlined in a). The main uncertainty is in the success of the polarization studies for both Venus and the moon but, if successful, the results should be very interesting.

d) "New Arecibo High Resolution Radar Images of Venus: Preliminary Interpretation", D.B. Campbell, A.A. Hine, J.K. Harmon, D.A. Senske, R.W. Vorder Bruegge, P.C. Fisher, S. Frank and J.W. Head, Abst. for 20th Lunar and Planetary Science Conf., March, 1989 (To be submitted to 'Science' in April).

"Orogeny and Large Scale Strike-Slip Faulting: Tectonic Evolution of Maxwell Montes, Venus", R.W. Vorder Bruegge, J.W. Head, D.B. Campbell, submitted to J. Geophys. Res., Dec. 1988.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Michael H. Carr  
(Name, Address, U.S.G.S., 345 Middlefield Rd., MS-946  
Telephone Number) Menlo Park, CA 94025 (415) 329-5174

CO-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE: Deuterium and the Mars Water Cycle

- a. Objectives. The over-all objective is to better determine the role that water has played the geologic and climatic history of the planet. Present estimates of the amount of water outgassed from the planet range from 3 m to over 1 km. If the low numbers are correct, then the model for the geologic history of the planet that has evolved over the last several years is wrong, for there would be insufficient water to form many of the features generally interpreted as having formed by water and ice. Recent measurements show that the D/H ratio of water in the martian atmosphere is 5.2 times the terrestrial value. The initial interpretations of this enrichment are difficult to reconcile with current interpretations of the planet's geologic history. The main objective of this proposal is to explore ways of reconciling the D/H enrichment with the geology. A secondary objective is to define conditions under which liquid water could exist close to the surface, thereby facilitating seepage and formation of valley networks.
- b. Accomplishments. New proposal
- c. Plans for FY-90. Emphasis in FY-90 will be on evaluating the implications of the deuterium enrichment in the martian atmosphere. Estimates will be made of how much water would enter the martian atmosphere during a typical flood, and how this would affect the D/H ratio in the atmosphere. A model will be explored in which the water in the atmosphere and water in the ground are essentially decoupled except for occasional events such as large floods. Special emphasis will be placed on assessing how secure the evidence is that the poles exchange significant amounts of water with the atmosphere. These approaches are all considered necessary in order to reconcile the D/H measurements with the abundant evidence for water action on the surface. When the deuterium work is complete work will start an assessing the ground conditions necessary for groundwater seepage.
- d. Recent relevant publications. Carr, M. H., Recharge of the early atmosphere of Mars by impact-induced release of CO<sub>2</sub> (in press, Icarus). Carr, M. H., 1988, The inventory of water on Mars. Astron. Vestnik, v. 22.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Philip R. Christensen  
Department of Geology  
Arizona State University  
Tempe, Arizona 85287 Ph. (602) 965-7105

CO-INVESTIGATORS: Dr. Donald Anderson

PROPOSAL TITLE: Thermal-Infrared Spectroscopy for Planetary Surfaces

### ABSTRACT:

- a) The objectives of this proposal are 1) to characterize the thermal-infrared spectra of candidate planetary materials in emission; and 2) to study the spectral properties of natural rocks, weathering products, and soils to develop analytical tools to interpret planetary observations. Thermal emission spectroscopy provides a powerful analytical tool for determining the composition of planetary surface materials. All silicates, carbonates, sulfates, oxides, phosphates, and other geologic materials have diagnostic absorption bands in the thermal-IR region. This proposal will measure the spectral characteristics of specific geologic materials in natural mixtures and realistic environments that are relevant to planetary surfaces. The work being performed here acquires spectra of materials in emission, which can be directly related to spectra measured from spacecraft instruments. This distinction is particularly important for studying mixtures of fine particles and thin coating on rocks where scattering plays an important role.
- b) Major accomplishments of the prior year include: 1) continued acquisition of mineral and rock samples in emission; 2) detailed studies of spectral properties of weathering coatings of varying thickness using rock samples collected in the Mojave and southwestern Arizona; 3) analysis of the effects of composition and vesicularity on volcanic glasses; 4) development of full emission spectra calibration algorithm.
- c) Future work: Effort on Task 1 will continue the study the thermal-IR spectra of candidate materials in emission over a range of particle size, packing, and surface characteristics. The emphasis will be on the relationship of thermal-IR spectra to the composition and physical properties of the surface and underlying rock. This work will expand the study of composition and textural variations in volcanic glasses. Effort on Task 2 will focus on two-component mixtures, beginning with simple mixtures of quartz and olivine, to provide data to a theoretical investigation of emission from powdered mixtures. Task 3 will continue the investigation of weathering products on natural geologic materials by SEM observations of a suite of coated rocks previously characterized by thermal spectral and petrologic analysis.
- d) Relevant Publications:  
Christensen, P.R. and S. Thliveris, 1989, Thermal-infrared spectral observations of coated surfaces, *Lunar Planet Sci.* XX, 155-156.  
Christensen, P.R., 1988, Thermal emission spectroscopy of planetary surfaces, Am. Chem. Soc. Abstracts, *in press*.  
Ondrusek, J., Christensen, and J.H.Fink, 1989, Composition and textural variations in lava from Glass Mountain, Calif.: Evidence from thermal spectroscopy, *Internat. Assoc. Volcanology and Chemistry of Earth's Interior, Abs. with Programs*, *in press*.  
Christensen, P.R. and A. Kahle, Thermal emission spectroscopy: Application to Earth and Mars, in Remote Geochemical Analysis: Elemental and Mineralogical Composition, C. M. Pieters and P.A.J. Englert eds., *in preparation*.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Philip R. Christensen  
Department of Geology  
Arizona State University  
Tempe, Arizona 85287  
(602) 965-7105

CO-INVESTIGATORS: Dr. David Krinsley  
Dr. Bruce Jakosky

PROPOSAL TITLE: Thermal Conductivity Measurements for Planetary Surfaces

### ABSTRACT

- a) The objectives of this proposal are: 1) to determine the dependence of thermal conductivity on the physical properties of a surface, including particle size, porosity, packing, and bonding; 2) to develop an analytical model of thermal conductivity of particulate surfaces; and 3) to relate thermal conductivity measurements to remote sensing observations. The thermophysical properties of Mars have been extensively mapped, and thermal observations have also been made of the Earth, the Moon, the asteroids, and the outer satellites. These observations can be related to the physical properties of the surface through laboratory measurements of thermal conductivity. A suite of observations has been previously performed for lunar and martian conditions. The purpose of this effort is to conduct a systematic investigation of the full range of expected planetary surface conditions, including mixtures of particle sizes, non-spherical particles, and bonded grains. Pore size and geometry, grain-grain contacts, and inter-grain bonding play the dominant role in controlling thermal conductivity at low pressures. It is proposed that these properties be investigated in relationship to conductivity measurements, and a model of their relative contributions be developed. These experiments and the resulting model will be particularly important for interpreting Mars Observer Thermal Emission Spectrometer observations to characterize martian surface properties.
- b) New proposal
- c) The results of this work will include: 1) a uniform matrix of thermal conductivity measurements at Mars pressures covering the full range of particle sizes and mixtures of particle sizes; 2) scanning electron microscope (SEM) observations of particle size, porosity, pore geometry, grain-grains contacts, and bonding which will be related to thermal conductivity; 3) an analytical model of thermal conductivity in particulate materials; 4) measurements of mixtures of particle sizes, which will be used to study natural surfaces; and 5) a determination of the effects of bonding and particle shape on thermal conductivity.
- d) Relevant Publications  
Presley, M.A. and P.R. Christensen, The distribution and origin of duricrust on Mars, *Lunar Planet Sci. XX*, 868-869.  
Christensen, P.R., 1986, Regional dust deposits on Mars: Physical properties, age, and history, *J. Geophys. Res.*, **91**, 3533-3545.  
Jakosky, B.M., 1986, On the thermal properties of martian fines, *Icarus*, **66**, 117-124.  
Jakosky, B.M., and P.R. Christensen, 1986, Global duricrust on Mars: Analysis of remote sensing data, *J. Geophys. Res.*, **91**, 3547-3559.  
Pye, K. and D.H. Krinsley, 1984, Petrographic examination of sedimentary rocks in the SEM backscattered electron detectors, *J. Sed. Pet.*, **54**, 877-888.  
Krinsley, D. and R. Greeley, 1986, Individual particle and martian aeolian action - A review, *Sed. Geology*, **47**, 167-189.

### PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Roger N. Clark  
(Names, Address, USGS, MS 964, Box 25046 DFC, Denver, CO 80225  
Telephone Number) (303) 236-1332; -1335; FTS 776-1332; -1335

CO-INVESTIGATORS: None  
(Name Only) \_\_\_\_\_

TITLE: Quantitative Remote Sensing of Mineral Abundance Using Reflectance Spectroscopy

ABSTRACT: (Single-spaced, type within box below. Paragraphs numbered (a) through (d) should include: (a) brief statement of the overall objectives and justification of the work; (b) brief statement of the progress and accomplishments of the prior year, or "new proposal"; (c) brief listing of what will be done this year, as well as how and why; and (d) summary bibliography):

a. We will study the surface composition of planetary surfaces by identifying species present and deriving their abundances. We will refine a non-linear least squares algorithm to solve for mineral abundance from remotely obtained reflectance spectra of planetary surfaces using scattering theories as well as studying the spectral properties of minerals and their mixtures. Such analysis techniques are feasible and very important for geologic remote sensing studies. Furthermore, with the advent of mapping spectrometer instruments, it will be possible to determine and map mineral abundances on a planetary surface. This research is vital to the understanding of data from the Galileo NIMS experiment, as well as future planetary spacecraft missions like Mars Observer, CRAF, Cassini and LGO.

b. During this last year, we made a major discovery of scapolite on Mars. Estimated scapolite abundances are very high (presumably in the dust). 30% or more! Analysis has been complicated by carbon monoxide absorption in the same spectral region. The spectrum of Callisto has been analyzed using a newly developed model for the simultaneous solution of intimate plus areal mixtures. The entire Callisto spectrum is being modeled from 0.25 to 4.5  $\mu\text{m}$ . The results explain the confusion in interpreting the amount of ice on Callisto.

c. The surface composition of outer solar system satellites and Mars will be analyzed in light of recently discovered absorption bands. The new analysis algorithms will be used in the above analyses, and their efficiency increased. Limitations and accuracy will be explored. More optical constants will be derived for geologically important minerals to be used in the above analyses.

d. Clark, R.N., R.B. Singer, G.A. Swayze, and A. Tokunaga, 1989, Discovery of Globally Distributed Scapolite on Mars. Fourth International Conference on Mars, Abstracts, Tucson AZ, Jan. 10-13, 1989, pp 82-83.

Clark, R.N., R.B. Singer, and G.A. Swayze, 1988, Mineralogy Indicated by the Martian 2.36- $\mu\text{m}$  Band, *Bull. Am. Astron. Soc.*, 20 p. 849.

Calvin, W.M., and Clark, R.N., 1988, Modeling the Reflectance Spectrum of Callisto 0.2-4.2  $\mu\text{m}$ , *Bull. Am. Astron. Soc.*, 20 p. 876.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:	Gary D. Clow
(Name, Address, Telephone Number)	U.S.G.S., 345 Middlefield Rd., MS-946 Menlo Park, CA 94025 (415) 329-5179
CO-INVESTIGATORS:	Robert M. Haberle
(Name Only)	
PROPOSAL TITLE:	Ice Sublimation Rates at the Surface of Mars

## Abstract

(a) Objective: Many geomorphic features on Mars have been explained in terms of processes involving water ice. The disposition of surface and near-surface ice is strongly influenced by sublimation rates, but previous estimates of these rates are very uncertain. Our objectives are to: 1) achieve a better understanding of water-vapor transport mechanisms under Martian conditions, 2) develop simple parameterizations for near-surface vapor transport specifically for Mars, and 3) calculate sublimation rates for a range of conditions to help elucidate the nature of the many putative ice-related features on the surface of Mars. The results will have implications for the polar caps, glaciers, snowpacks, lakes, frozen ground, the Mars water cycle, and atmospheric evolution.

(b) Progress: A near-surface, water-vapor transport model, based on modern boundary-layer theory, has been completed for Mars. The model can be used for a full range of surface textures, wind speeds, and atmospheric stabilities. The operating conditions for the self-buoyancy sublimation mechanism have been identified. Water-vapor transfer coefficients have been determined for Martian conditions, on the assumption of neutral atmospheric conditions.

(c) Work Plan FY90: Simple parameterizations for near-surface, water-vapor transport will be developed specifically for Mars. A full range of atmospheric pressures will be considered. Parameterizations biased to account for local atmospheric stability cycles will be developed for the Viking Lander sites, the polar caps, and nonpolar snow/ice deposits. The range of values for a critical parameter, the friction velocity, will be established for various sites. Sublimation rates from the north residual polar cap will be recalculated to assess its role in the current Martian water cycle.

(d) Summary Bibliography:

- Clow, G.D., and others, 1988. Climatological observations and predicted sublimation rates at Lake Hoare, Antarctica, *J. Climate*, 1, 715-728.
- Haberle, R.M., and B.M. Jakosky. Sublimation and transport of water from the north residual cap on Mars, submitted to *J. Geophys. Res.* March 1988.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Christopher D. Condit  
(Name, Address, Dept. of Geology/Geography  
Telephone Number) Univ. of Massachusetts  
Amherst, MA 01003 413-545-0245

Co-INVESTIGATORS: -  
(Name Only)

Title: GEOLOGIC MAPPING OF SOUTHWEST-CENTRAL MC-3 QUADRANGLE, MARS

ABSTRACT: (Single-spaced, type within box below. Paragraphs numbered (a) through (d) should include: (a) brief statement of the overall objectives and justification of work; (b) brief statement of the progress and accomplishments of the prior year, or "new proposal;" (c) brief listing of what will be done this year, as well as how and why; and (d) summary bibliography):

- a. The objective of this proposal is to produce a series of three 1:500,000-scale geologic maps of the southeastern area of Alba Patera (quadrangles MTM 35102, MTM 35107, MTM 40107), focusing on an evaluation of: the age relations within the Alba Patera lava flows and their relation to the grabens and to surrounding units; the differences in geologic history between these flows; the structural history of the large grabens associated with Alba Patera and their relation to the evolution of Alba Patera and the regional tectonic history; any systematic relations between pit-craters associated with some of the grabens of Tantalus Fossae, which may provide information on the mechanism of pit (or graben) formation. SEE NAGW-1236
- b. Geologic map of MTM 35102 has been completed and is in review; results have been reported at the Lunar and Planetary Conference XX (Condit, 1989). Major findings include support for the hypothesis of Mouginis-Mark et al. (1986) that Alba Patera is a transitional volcano from pyroclastic dominated older patera to the more recent flow dominated volcanoes of the Tharsis Montes, and that no subsidence was evident during the eruption of the youngest flows of the middle member of the Alba Patera Formation. In addition, two of the three graben sets recognized appear to be of regional origin; concentric grabens are suggested to be of local volcanotectonic origin; and pit craters and associated regional N30°E grabens are proposed to have either formed early in the deformational history, or if later on reactivated structures to be the result of fractures much deeper than those of other two recognized graben sets.
- c. Complete detailed geologic map of MTM 35107 (materials for this work have not been received) and complete detailed geologic map of MTM 40107 (this proposal renewal) to continue analysis of flow and tectonic history on southeast flank of Alba Patera; synthesize and publish analysis for all three quadrangles; coordinate detailed photoclinometric work with other scientists on graben and graben-pit formation based structural groups define in this study.
- d. Condit, C.D., (in review), Geologic map of quadrangle 35102, southeast Alba Patera, Mars, (1:500,000): U.S. Geol. Survey Misc. Map.
- Condit, C.D., (1989), Volcanotectonic patterns on the southeast flank of Alba Patera: Proc. Lunar Planet. Sci. Conf. XX, p. 181-182.
- Mouginis-Mark P.J., Wilson, L., and Zimbelman, J.R., (1988), Polygenetic eruptions on Alba Patera, Mars: Bull. Volcanol., p. 19-37.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Joy A. Crisp  
Jet Propulsion Laboratory  
California Institute of Technology  
4800 Oak Grove Drive  
Pasadena, CA 91109

CO-INVESTIGATOR: Stephen M. Baloga

PROPOSAL TITLE: RHEOLOGY OF PLANETARY LAVA FLOWS

### ABSTRACT:

**A.Objectives** The objectives are to investigate the effects of cooling and crystallization on the rheology and morphology of lava flows on Earth, Mars, and the Moon, and to determine the relationship between the crystallinity of a solidified lava flow and the rheology of the flow during emplacement. We are presently unable to use theoretical models to predict the geomorphology of lava flows, in part, because of a lack of understanding regarding rates of crystallization and degassing and their effects on rheology. Fundamental research on the basic physics of crystallization and its effect on magma rheology is required to make new progress in the interpretation of lava flows. The results of the study of crystallinities of terrestrial flows and the combinations of theoretical models will be applied to martian and lunar lava flows to infer eruptive, compositional, and rheologic parameters. **B.Accomplishments** The development of a mathematical model for the cooling of lava flows with two thermal components. Application of the model to martian flows to estimate eruption rate. **C.Proposed Work:** (1) Measure crystal size distributions and abundances in samples of the 1984 Mauna Loa flow and infer crystallinity for the active flow, as a function of time and position in the flow (2) Use the crystal size distributions to estimate rates of crystal growth and nucleation, (3) Relate crystallinity to viscosity and yield strength using the results of laboratory viscometry experiments, (4) Calculate the importance of the various thermal processes on the rheology of lava flows, (5) Measure dimensions and thicknesses of leveed and sheet flows on Mars and the Moon, and (6) Use the results of the crystallinity and rheology studies and combine theoretical models for lava flow emplacement to constrain eruptive and rheologic parameters for planetary lava flows. **D. Summary bibliography:** Baloga, S. and J. Crisp (1988) Simulations of lava flows on Mars, NASA MEVTV Working Group Meeting: Volcanism on Mars, June, 1988, p.27-29. Crisp, J. and S. Baloga (1989) Estimating eruption rates of planetary lava flows, submitted to 20th Proceedings LPSC. Crisp, J. and S. Baloga (1989) A model for lava flows with two thermal components, submitted to JGR.



## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Jeffrey N. Cuzzi  
(Name, Address, NASA Ames Research Center, M.S. 245-3  
Telephone Number) Moffett Field, CA 94035 (415) 694-6343

Co-INVESTIGATORS: Richard H. Durisen, Mark R. Showalter  
(Name Only) H. Luke Dones

PROPOSAL TITLE: Planetary Ring Studies

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a) This research consists of integrated theoretical and observational studies of the dynamics, morphology, and particle properties characterizing planetary ring and satellite systems.
- b) Our model of longitudinal variation of meteoroid impact properties was refined, strengthening the relationship of impacts to spoke creation. We demonstrated that inward drift due to loss of angular momentum associated with meteoroid bombardment may be the dominant "short timescale" problem for rings of macroscopic particles away from density waves (Saturn's C ring, the Uranian rings in general, the unseen source of the Jovian ring). We improved our ballistic evolution code, including a distribution of ejecta directions and velocities, and began using it in realistic modeling of fine structure and its suppression by viscosity. We initiated study of the variation of spatial scales in the B and A ring irregular structure. We obtained new results on the particle properties at the inner edges of the B and A rings. We obtained new constraints on the abundance of material in and around the G and E rings of Saturn.
- c) Meteoroid bombardment, erosion, transport, and contamination processes, and their dependence on ring particle size and optical depth, will be studied further, including the effects of alternative dynamical projectile populations. The A and B ring inner edge work will be completed and written up, and irregular structure will be studied with maximum entropy techniques. the faint rings of Uranus will be further analyzed. We will begin development of a viscous model of ring shepherding.
- d) J.N. Cuzzi and R.H. Durisen (1989) Bombardment of planetary rings by meteoroids: General formation and effects of Oort cloud projectiles; Icarus, submitted R.H. Durisen et al (1989) Ballistic transport in planetary ring systems due to particle erosion mechanisms. I: Theory, numerical methods, and illustrative examples; Icarus, in press; B. Flynn and J.N. Cuzzi (1989) Structure in the Cassini Division of Saturn; Icarus, in press; L.R. Doyle et al. (1989) Radiative transfer modeling of Saturn's B ring; Icarus, in press.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Jeffrey N. Cuzzi  
(Name, Address, NASA Ames Research Center, M.S. 245-3  
Telephone Number) Moffett Field, CA 94035 (415) 694-6343

Co-INVESTIGATORS: Joelle Champney, Anthony Dobrovolskis  
(Name Only) Thomas J. Coakley

PROPOSAL TITLE: Particle-gas Dynamics in the Protoplanetary  
Nebula

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) This research consists of theoretical modeling of the coupling between the spatial and velocity distribution of both particle and gas phases in the early stages of the protoplanetary nebula. b) We have implemented viscous transport in 1- and 2-D two phase models which determine the 3-D mean velocity profiles of coupled particle and gas phases in the protoplanetary nebula. Viscous stresses produce an outward directed flow just above the main particle layer, which itself drifts inward. For particles smaller than a meter or so in radius (at least), the particle layer generates sufficient turbulence to prevent gravitational instability from occurring. These results are fully self consistent, since we determine the turbulent viscosity generated by the mean velocity shear as the particle layer evolves. We also developed a simple but physically reasonable model for the diffusion coefficient of particles as a function of their size and the local properties of the nebula (the "Schmidt number"). c) We will proceed to thoroughly explore our two parametrizations of viscosity. Our "zero-equation" model is simpler, but our "two-equation" model gives us more realistic results - especially in dense particle layers which are approaching gravitational instability. We will validate our viscous models by comparison with known analytic solutions. We will refine our Schmidt number model and verify it with laboratory data. We will explore the evolution of the protoplanetary nebula during the stage when particles grow from microscopic to planetesimal sizes by varying our (single) particle size. We will investigate a range of potential nebula properties which affect the shear and therefore the turbulence. d) Cuzzi, J.N., J.M. Champney, T. Coakley, and A.R. Dobrovolskis (1989) Particle-gas dynamics in the protoplanetary nebula; Abstracts LPSC, XX, part 1, 216-217; Champney, J.M., J.N. Cuzzi, and T.R. Coakley (1989); A turbulent two-phase model for nebula flows (in preparation)

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: DONALD R. DAVIS  
(Name, Address, Planetary Science Institute  
Telephone Number) 2030 E. Speedway Suite 201, Tucson, AZ 85719  
(602) 881-0332  
Co-INVESTIGATORS: Dominique Sbaute and Stuart J. Weidenschilling  
(Name Only)

PROPOSAL TITLE: COLLISIONAL DISRUPTION IN THE SOLAR SYSTEM:  
ASTEROID EVOLUTION AND EXPERIMENTAL STUDIES

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) Goals: This program investigates the collisional and cratering history of the solar system. We develop and apply numerical models of the collisional evolution of asteroids. We apply observational constraints on the size and rotation distribution of asteroids, the number of dynamical families, planetary cratering histories, and the frequency of asteroids thought to be formed by collisional disruption in order to understand which asteroid characteristics are the product of their collisional history and which are primordial in origin. We also carry out collisional disruption experiments in order to obtain the experimental data necessary to develop numerical algorithms for collisional outcomes.

b) Recent Progress: A new model for the spin rate of partially dispersed cores was developed, completing our comprehensive algorithm for asteroid spin changes due to collisions. This algorithm was incorporated into our numerical code and applied to study the simultaneous size and spin evolution of asteroids. We also completed and tested a version of our numerical model which treats two interacting populations having different material properties and/or orbit distributions. We prepared a manuscript describing this new model and the effects of collisions on asteroid rotation rates. There were two additional publications concerning asteroid traits related to collisional evolution (size distribution and families). Finally, a multi-year project on a book about the planet Mercury culminated in publication of "Mercury" two months ago. Under the experimental program, we reduced and analyzed experimental data on the fragmentation of aggregate targets and on the mass-velocity distribution of fragments from collisional disruption experiments. Two manuscripts are in preparation on this work.

c) Proposed Research: In the asteroid collision task, we will determine the collisional history of asteroids that satisfies all observational constraints using our integrated size-spin model. We propose to develop a detailed algorithm that models asteroid collision rates as a function of orbit elements and apply this algorithm in our numerical model to study collision mixing in the asteroid belt, differential effects between the inner and outer belt, and the amount of mass that could be removed through resonance mechanisms over solar system history. We will also study traits of planetary crater populations that bear on the asteroid size distribution and collisional processes. In the experimental task, we will carry out collisional disruption experiments to study the effects of target structure and projectile/target strength differences on collisional outcomes. We will also carry out experiments in association with colleagues designed to test aspects of our current scaling laws.

d) Summary Bibliography: In the past year we produced or contributed to 10 papers or manuscripts, 1 book, 4 abstracts or progress reports and made 3 oral presentations. Recent papers are: Asteroid Collisional History: Effects on Sizes and Spins, D.R. Davis, S.J. Weidenschilling, P. Farinella, P. Paolicchi, and R. Binzel, in press, Asteroids II (R. Binzel, M.S. Matthews, and T. Gehrels, eds.) Univ. of Arizona Press. On Collisional Disruption: Experimental Results and Scaling Laws, D.R. Davis and E.V. Ryan, in press, Icarus, 1989.

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## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Philip A. Davis  
(Name, Address, U.S.G.S., 2255 N.Gemini Dr., Flagstaff, AZ  
Telephone Number) FTS 765-7201 (602) 527-7201  
CO-INVESTIGATORS: Kenneth L. Tanaka  
(Name Only) Jeffrey B. Plescia

PROPOSAL TITLE: Mars' Geology and Morphology

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objectives: The objectives of this proposal are to obtain and to use photoclinometric-profile data for a variety of tectonic features on Mars to estimate (1) from grabens, the thickness of the faulted layer, the amount of extension and strain, and the variation of these parameters with time and space; (2) from pit chains, mechanisms for pit formation and the relations between pit formation, local regolith thickness, and graben formation; and (3) from wrinkle ridges, the amount of regional crustal shortening and strain, and how these factors are related to the local geologic setting.

(b) Accomplishments: During the 6 months since this proposal was funded, we have finished our morphometric examination of tectonic and collapse features at Lunae, Syria, and Sinai Plana. Detailed morphometric data from this study strongly corroborate a mechanical discontinuity at a depth of about 1 km and suggest the existence of two other discontinuities at 0.3-0.6 km and at 2-3 km. We have also completed a detailed photogeologic study of the sequence of tectonism at Alba Patera in preparation for our morphometric analysis of this area. We have also obtained in excess of 350 profiles across wrinkle ridges in Lunae Planum and Amazonis Planitia, which indicate a total shortening of a few kilometers across Lunae Planum, and therefore, a total compressional strain between 0.2 and 0.5% across Lunae Planum.

(c) Work Plan (FY90): Three tasks are identified. Task 1: to determine the amount and timing of extension and the thickness of the faulted layer around Alba Patera and possibly around Mareotis and Tempe Fossae. Task 2: to examine genetic relations of associated pit chains and erosional features in these three areas. Task 3: to define the magnitude and timing of regional crustal shortening and the amount of strain around the northern Tharsis region as reflected in wrinkle ridges.

(d) Recent Bibliography: Tanaka, K.L., and Davis, P.A. (1988) Tectonic history of Syria Planum province of Mars: J. Geophys. Res. 93, 14.893-14.917; Davis, P.A., and Golombek, M.P., Discontinuities in the shallow Martian crust, Lunar and Planetary Science XX, 224-225; Rotto, S.L., and Tanaka, K.L., Faulting history of the Alba Patera-Ceraunius Fossae region of Mars, Lunar and Planetary Science XX, 926-927; Golombek, M.P., Plescia, J.B., and Franklin, B., Faulting and folding in the formation of planetary wrinkle ridges: submitted to J. Geophys. Res.; Golombek, M.P., and Plescia, J.B., 1989, Subsurface structure of Martian wrinkle ridges: Program and Abstracts, 4th International Conference on Mars, 113-114.

## PROPOSAL SUMMARY SHEET--ABSTRACT

### PRINCIPAL INVESTIGATOR:

Dr. Rene A. De Hon  
Department of Geosciences  
Northeast Louisiana University  
Monroe LA 71209  
(318) 342-2188

CO-INVESTIGATORS:       None

PROPOSAL TITLE:       Martian Sedimentary Deposits

### ABSTRACT:

#### A. OBJECTIVES:

This proposal requests continued funding for studies in planetary geology. The chief area of investigation for the past year have been a detailed history of the events related to the formation of Maja Vallis complex. Current studies have emphasized martian fluvial geomorphology and sedimentation.

#### B. ACCOMPLISHMENTS:

During the past year emphasis has been placed (1) on the erosional and sedimentary history of Maja Vallis and (2) on the occurrence of martian lakes. Preliminary arguments have been presented at the Lunar and Planetary Science Conference, Annual Meeting of Geological Society of America, and the Fourth International Mars Conference.

#### C. TASKS:

The PI continues the tasks focused on (1) erosion and sedimentation by surface water on Mars, (2) models of the surface flow of water on Mars, (3) characterization of sedimentary deposits, (4) mechanisms of release of subsurface water, and (5) sedimentation in the northern plains of Mars.

#### D. RECENT PUBLICATIONS OR PRESENTATIONS:

De Hon R.A., 1988, Martian Transverse Valleys: Geol. Soc. Amer. Mtg., Denver.

De Hon R.A., 1989, Flood surge in martian outflow systems: Episodic flow: Lunar Planet. Sci. Conf. XX, p. 230-231.

De Hon R.A., A.C. Leith, and W.B. McKinnon, 1989, A geologic map and photomosaic of the Jg-15 quadrangle of Ganymede: Lunar Planet. Sci. Conf. XX, p.234-235.

De Hon R.A., 1989, Martian Lacustrine Plains: 4th Mars Conference.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Stanley F. Dermott  
(Name, Address, 420 Space Sciences Bldg., Cornell University  
Telephone Number) Ithaca, NY 14853-6801 (607) 255-5895

Co-INVESTIGATORS: Prof. Philip D. Nicholson  
(Name Only) Dr. Peter C. Thomas

PROPOSAL TITLE: "Dynamics of Satellites and Dust Particles"

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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a. Objectives: 1. To investigate the dynamics of resonance, particularly temporary trapping and chaotic motion, in the satellite systems of Saturn and Uranus, in order to determine the orbital and thermal histories of the satellites. 2. To measure the shapes of satellites in order to place constraints on their mean densities and internal structures. 3. To investigate the orbital evolution of dust particles in the solar system in order to determine the origin of the dust particles in the zodiacal cloud and to account for the IRAS dust band observations.

b. Progress: 1. We have investigated the role of secondary resonances in the orbital evolution of Miranda and estimated the maximum eccentricity that the satellite had in the past. 2. We have determined the shape of Tethys. 3. We have written all the software needed to model the IRAS dust bands.

c. Work Statement: 1. Investigate the evolution of resonances under the action of very low drag rates. 2. Determine the shape of Ariel. 3. Analyse the new high resolution IRAS Zodiacal History File.

d. Bibliography:

1. Malhotra, R. K. Fox, C.D. Murray and P.D. Nicholson. (1989). Secular perturbations of the Uranian satellites: Theory and practice. Astron. Astrophys. (in press).
2. Malhotra, R. and S.F. Dermott. (1989). The role of secondary resonances in the orbital history of Miranda. Icarus (to be submitted).

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: William B. Durham  
(Name, Address, University of California, Lawrence Livermore  
Telephone Number) National Laboratory, Livermore, CA 94550  
(415) 422-7046

Co-INVESTIGATORS: Stephen H. Kirby  
(Name Only)

PROPOSAL TITLE: Rheologies of planetary ices

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Voyager images of the icy moons of Saturn and Uranus, showing tectonic activity as intense as on the Galilean satellites, indicate that those moons contain material which has a softer rheology than that of pure H<sub>2</sub>O ice. Cosmological considerations suggest that NH<sub>3</sub> is present in planet-wide concentrations as high as NH<sub>3</sub>/(NH<sub>3</sub>+H<sub>2</sub>O) = 0.15. CH<sub>4</sub> may also be present mainly as a clathrate. To aid in the interpretation of geologic features on the surfaces of the Saturnian and Uranian satellites and to help understand the evolution of their interiors, we propose to measure in the laboratory the rheology of CH<sub>4</sub>-H<sub>2</sub>O under conditions of pressure and temperature that exist on and within the icy satellites. We also propose to pursue unanswered questions concerning the rheology of NH<sub>3</sub>-H<sub>2</sub>O mixtures. In addition, we plan to extend our work on the flow laws of H<sub>2</sub>O ices to include ice VI, which is likely to be an important phase in the interiors of the larger icy moons.

(b) In the past year we measured the rheological behavior of NH<sub>3</sub>-H<sub>2</sub>O mixtures over a wide range of conditions to broadly constrain the behavior of such mixtures on the outer satellites. Confining pressures ranged from 0.1 to 100 MPa, temperatures from 130 to 180 K, and NH<sub>3</sub> content from 1 to 29% by weight. We extended an earlier study on mixtures of ice+rock to include volume concentrations of rock up to 56%, and presented the results at LPSC XX. We designed, constructed, and calibrated an assembly for molding samples of methane clathrate under CH<sub>4</sub> gas pressures as high as 20 MPa.

(c) The principal goal of the coming year will be to identify broad patterns of rheological behavior in the CH<sub>4</sub>-H<sub>2</sub>O-system, in the manner of experiments during the past year in the NH<sub>3</sub>-H<sub>2</sub>O system. We also plan to complete and publish the work on the NH<sub>3</sub>-H<sub>2</sub>O system, pursuing textural and chemical analyses of deformed samples and doing a few deformation experiments as needed. Finally, we plan to design and order a 1.0-GPa pressure vessel, in order to measure the rheology of ice VI.

(d) W.B. Durham, S.H. Kirby, H.C. Heard, L.A. Stern, and C.O. Boro, Water ice phases II, III, and V: Plastic deformation and phase relationships, *J. Geophys. Res.*, 93, 10191-10208, 1988. S. H. Kirby, W. B. Durham, M. L. Beeman, H. C. Heard, and M. A. Daley, Inelastic properties of ice I<sub>h</sub> at low temperatures and high pressures, *Journal de Physique*, 48, suppliment (Proc. VIIth Symposium on the Physics and Chemistry of Ice, Grenoble, France), 227-232, 1987. W.B. Durham, S.H. Kirby, and L.A. Stern, Rheology of water-ammonia ice (abstract), *Lunar Planet. Sci. XIX*, 285-286, 1988. W. B. Durham, S. H. Kirby, L. A. Stern, and K. A. Ragaini, Brittle and ductile behavior of ice/rock mixtures (abstract), *Lunar Planet. Sci. XX*, 254-255, 1989.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Wolfgang E. Elston  
(Name, Address, Department of Geology, University of New Mexico  
Telephone Number) Albuquerque, New Mexico 87131  
(505)-277-5339

Co-INVESTIGATORS: David Twist  
(Name Only)

PROPOSAL TITLE: Application of Volcanology to Lunar and  
Planetary Geology

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

ABSTRACT (a) Objectives: Investigation of the 2.1 Ga Bushveld Complex, South Africa, to determine possible origin by multiple impact of a disintegrating comet or asteroid into a tectonically stable shallow marine basin. Bushveld Complex is the only proposed terrestrial impact structure comparable in size to a small lunar mare. Impact excavated a cavity beneath solidus isotherm of granite, generating Rooiberg Felsite by partial melting of the crust. Research is focused on Rooiberg Felsite, the largest known mass of siliceous volcanic-like rock on Earth (~300,000 km<sup>3</sup>). It has no known sources, grades into sedimentary basement rocks, and has unique textures indicative of superheating, followed by quenching and undercooling. (b) Accomplishments of Prior Year: (1) Revisions of structure of Bushveld Complex from new geological and geophysical data, interpretation of structure in terms of impact models; (2) petrographic studies of Rooiberg Felsite, target rocks, and gradations between them; (3) geochemical mixing models to test derivation of Rooiberg Felsite from sedimentary and crystalline crustal rocks. (c) Proposed Research: (1) Petrography, mineralogy, chemical composition and isotopic composition of Rooiberg Felsite, in order to model its origin, cooling history, mode of eruption, transport, and emplacement, and cooling history. (2) Structure of the Bushveld Complex by integration of geological and geophysical data, including field work to determine the nature of deformation of the pre-Bushveld basement and to establish a facies model for Rooiberg Felsite. (d) Publications - Published 1 paper, 2 abstracts. In press: 1 paper, 1 abstract



## PROPOSAL SUMMARY

A.W. England, Principal Investigator  
F.T. Ulaby, Co-investigator  
Radiation Laboratory  
Department of Electrical Engineering  
and Computer Science  
The University of Michigan  
Ann Arbor, MI 48109-2122  
Ph: (313) 764-0500

Title: **THEORETICAL AND EXPERIMENTAL MODELS OF  
THE DIFFUSE RADAR BACKSCATTER FROM MARS**

### ABSTRACT

- a) Our objective is to develop a theoretically and experimentally consistent explanation for the diffuse component of radar backscatter from Mars. The strength, variability, and wavelength independence of Mars' diffuse backscatter are unique among our Moon and the terrestrial planets. This diffuse backscatter is generally attributed to wavelength-scale surface roughness and rock clasts within the Martian regolith. Through the combination of theory and experiment, we would bound the range of surface characteristics that could produce the observed diffuse backscatter, and, by geologic inference based upon Viking and other analyses, develop regional scattering models for Mars.
- b) This is a new proposal.
- c) During the first year, we would gather the existing radar backscatter data, develop computational models for backscatter and emission from random, scaling surfaces, and develop scaled analogs of Mars random surfaces. Both fine-scale roughness and rock clasts contribute to the diffuse backscatter. Our initial focus is upon the contribution of the fine-scale roughness because it constitutes a background for the overall, diffuse backscatter. The combination of theoretical and experimental modeling serves to reduce the uncertainty that is inherent with any modeling approximation.
- d) Relevant publications:

England, A.W., "Characterization of Rough Surfaces," Proc. of Workshop on Ground Probing Radar, May 24-26, 1988, Ottawa, Canada, in press.

England, A.W. and G.R. Johnson, "Spectral Gradient of Lunar Radiobrightness--Heat Flow or Volume Scattering?" J. Res. U.S.G.S., Vol. 6, pp. 505-509.

Ulaby, F.T., R.K. Moore and A.K. Fung, "An Introduction to Random Surface Scattering and emission," Microwave Remote Sensing--Active and Passive, Vol. II, Addison-Wesley, pp. 922-1033.

## PROPOSAL SUMMARY

### PRINCIPAL INVESTIGATOR:

Von R. Eshleman, Professor  
Center for Radar Astronomy  
Stanford University  
Stanford, CA 94305-4055

**TITLE:** Theoretical Studies of the Radar Properties of the Icy Galilean Moons of Jupiter

**ABSTRACT:** (a) We propose to continue research into the explanation for the anomalous properties of radar echoes from the three icy Galilean moons of Jupiter -- Europa, Ganymede, and Callisto. These are the brightest known solid objects in the solar system in terms of radar albedo. An understanding of their radar properties is needed in order to develop a deeper understanding of the geophysical characteristics of the surfaces of these moons as well as other less well studied icy bodies in the outer solar system, and for the design of radar mapping missions to these bodies.

(b) In the past year we have refined the relationships between previously obtained non-coherent radar data and the buried-crater model that we first introduced in 1986. A good fit to the gross features in the data is achieved using very simple assumptions regarding the model parameters. However, the computations that are needed for this comparison are quite involved. Coherent radar data have been obtained for the first time under NSF funding for our participation in the 1987 and particularly the November-December 1988 campaign at the Arecibo Observatory. In anticipation of the use of these new data in our NASA studies, we have initiated and progressed in the development of the general relationships amongst: (1) the four Stokes parameters needed to completely characterize the instantaneous and average returns; (2) the measured coherent voltages for orthogonal circular and orthogonal linear polarizations of the echoes; and (3) the characteristics and predictions of the buried-crater model. We have also progressed in the ongoing effort to relate radar properties to physical descriptions of the surfaces, and in consideration of possible modified or new models for explaining the measured results.

(c) During the next year we propose to complete the reduction and initiate the interpretation of the November-December 1988 coherent data in the context of the Stokes parameters and their model implications. A more complete computer solution of the predicted degree of polarization will be developed for comparison with the measurements. Additional model fitting will be conducted using statistical variations in parameters such as cratering density, refractive index ratio, and surface roughness. The theory will be expanded to include predictions for bistatic radar measurements such as may be possible in a preliminary way with the Galileo orbiter. We are proposing to NSF that we participate in the December 1989 campaign at Arecibo, primarily because the 1988 data were limited to half-power by power-supply problems and because our data studies thus far indicate that more emphasis should be placed on linearly-polarized measurements. We note that new radar data obtained by others for the summer south polar cap of Mars display anomalous characteristics akin to those of the icy Galilean moons. This suggests possible common properties of planetary surfaces of CO<sub>2</sub> ice and H<sub>2</sub>O ice, and this merits further study.

(d) The appendices include abstracts of our two icy-moon papers presented at the 1988 DPS meeting, the final draft of our paper on this subject to be published by Pergamon Press in the Outer Planets section of the proceedings of the 1988 COSPAR conference, and a preprint of our paper on the atmosphere of Pluto. This last item is included because of a possible connection of the radar evidence with the conditions of vapor-pressure equilibrium that may be shared by the Mars polar caps, by Pluto, and by the icy Galilean moons.

## PROPOSAL SUMMARY

P.I. Larry W. Esposito  
LASP CB 392  
University of Colorado  
Boulder, CO 80309-0392

Title: Dynamics of outer planet rings

### ABSTRACT:

a. The Voyager occultations provide several uniform and high quality data sets for the rings of Saturn and Uranus. The spatial resolution is generally better than 100 m and the wavelengths of observation range from  $.13\mu$  to 13cm. We propose to study and inter-compare these data and develop theoretical models for particle size and particle transport.

b. Particle sizes in Saturn's rings. We have completed development of automated methods to intercompare Voyager Saturn radio, UVS and PPS ring occultations. We have fitted two models to these data: a power law size distribution extending from micron to meter-size particles; and a power law for particles larger than several microns combined with a gamma distribution of submicron particles. These results imply variations among the rings in dust content and the creation of small particles at density wave locations.

Numerical simulation of multiple particle size narrow rings. We have extended our Markov formulation to systems composed of two particle sizes. The larger particles are 8 times more massive than the small particles. These simulations show the development of sharper edges than for rings composed of particles of a single size. Furthermore, the tendency for equipartition results in a slower overall spreading rate for a narrow ring. Two papers accepted for publication in Icarus.

c. We will use the Voyager occultation data to derive consistent models of the size distribution and its variation in Saturn's rings, with special attention to density wave locations and differences among the main rings. We will include non-axisymmetric perturbations in our Markov process simulation of particle dynamics and apply it to explain sharp ring edges observed in Saturn and Uranus rings.

These results have implications for the structure and longterm evolution of planetary rings.

d. Summary bibliography (CY88): 3 papers published or in press; 8 abstracts.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Fraser P. Fanale  
(Name, Address, Planetary Geosciences Div., Hawaii Inst. of Geophysics  
Telephone Number) Univ. of Hawaii, 2525 Correa Rd., Hon., HI 96822  
(808) 948-6488

Co-INVESTIGATORS: None  
(Name Only)

PROPOSAL TITLE: Volatiles in Planetary Regoliths, NAGW 133

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Our objectives are to investigate the evolution of volatile systems on planetary bodies and the interaction of volatiles with planetary surfaces.

(b) We completed a paper entitled 'The Water Regime of Asteroid Ceres'. A model was developed to compute temperatures, H<sub>2</sub>O fluxes and ice depths as a function of latitude and time, as well as global water supply rates from the subsurface and planetary water loss rates due to thermal escape, photodissociation and sputtering. We found that ice could have survived to the present at depths of 10 to 50 m at the equator and at depths of 1 to 10 m at 50 L. The current subsurface supply rate was found to be between 30 to 240 g/s. Thermal escape of water has prevented the evolution of any significant atmosphere, and our results indicate that no ice at the average albedo of Ceres could exist below 80 L. This paper has been accepted by Icarus.

We completed a paper entitled 'The Loss of Water from Phobos'. A variation of the model for Ceres was used to compute temperatures, H<sub>2</sub>O fluxes and ice depths as a function of latitude and time. Our results indicate that Phobos is presently outgassing with a water flux between  $10^{**}(-13)$  and  $10^{**}(-12)$  g/cm<sup>2</sup>-s, and that ice has survived to the present at the equator at depths of .6 to 2.8 km, depending on the porosity and pore size of Phobos. This paper will soon be published in G.R.L.

(c) We will use our previous work (Fanale and Salvail 1987) to investigate the role of CO in comet activity and in the chemical differentiation of the nucleus. Since our original work in this area, several observations have indicated that CO is more prevalent than CO<sub>2</sub> in comet nuclei, and this may explain comet activity at large heliocentric distances. We will compute temperatures, H<sub>2</sub>O and CO fluxes and the depth of CO ice as a function of heliocentric distance. The stability of the surface layer of H<sub>2</sub>O ice as well as the possible emission of H<sub>2</sub>O ice grains will be considered.

We will continue and extend our investigation of the water regime of Phobos. Our original model will be refined by including the effects of a time varying obliquity and solar luminosity. The more complicated computations of temperature, water fluxes and ice depths due to these factors will be handled in a manner similar to that presented in Fanale et al. (1986). The effects of topography will be considered by performing calculations for points inside a crater, which may experience higher zenith angles and shadowing by the crater walls. Results will be obtained for two initial water distribution scenarios and three values for the initial endowment of water ice.

We will calculate the gas and dust output for the orbits of two comets, Kopff and Wild 2, which are the most likely candidates for the CRAF mission. Our existing program will be used to compute temperatures and gas and dust fluxes throughout the orbits of these comets for the known orbital and rotational parameters and a specified composition. Results will be obtained for various values of thermal conductivity and nucleus radii and will be related to possible future observations from spacecraft.

(d) Fanale et al. (1986); Fanale and Salvail (1987). (see reference list)

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Fraser P. Fanale  
(Name, Address, Planetary Geosciences Div., Hawaii Inst. of Geophysics  
Telephone Number) University of Hawaii, 2525 Correa Rd., Hon., HI 96822  
(808) 948-6488

Co-INVESTIGATORS: None  
(Name Only)

PROPOSAL TITLE: Volatiles on Outer Planetary Satellites, NAGW 633

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Our objective is to investigate the evolution of the interiors, surfaces, and atmospheres of the outer planetary satellites.

(b) We have applied our "ice greenhouse" model to Europa, and a manuscript of our completed work has been submitted to *Icarus*. We conclude that the "ice greenhouse" effect is important for porous water ice having a low thermal conductivity, and/or very translucent ice that allows significant sunlight penetration below the surface. The effect is greatly mitigated by volume sublimation. If the ice is sufficiently translucent, temperatures close to the melting point of water ice can be achieved a few centimeters below the surface. We have also begun our development of a hemispherical cold trap model for Io. We are developing a numerical model for SO<sub>2</sub> sublimation and deposition on Io to investigate the stability of regional cold traps under a variety of atmospheric regimes. Our initial results indicate that surface cold traps are more efficient than regional cold traps of high albedo surface material.

(c) In our original "ice greenhouse" model, we assumed thermal conductivity and sunlight extinction were constant quantities, whereas in reality these parameters depend on the properties of the medium. We will use the method of Clark et al. (1983) to calculate the growth of ice grains over time, and use this information to better constrain our model. We will also take into account impact stirring of the regolith.

Our model of the "solid state greenhouse effect" is sufficiently complex, and the results sufficiently important, to require experimental verification. We propose to collaborate with Matson and Brown to test the model. We will utilize an apparatus we have used in the past with great success to check the theory of vapor diffusion through a highly adsorbing medium. We will obtain experimental data for temperatures and mass fluxes for various conditions, and will modify our model using measured values of optical transmission properties as a function of wavelength.

We will apply our "ice greenhouse" model to the Saturnian satellite Enceladus. This satellite has an albedo exceeding 90%, and is believed to have a surface of almost pure ice. Part of the surface appears to have been resurfaced, which requires a source of heat which has not been explained by any conventional thermal model. We believe the "ice greenhouse" may be able to provide this additional heating. We will use our model to compute near surface temperatures for a variety of cases of thermal conductivity and sunlight extinction coefficients.

As a basis for understanding the geological implications of our thermal models, we will reexamine the question of whether the melting point of Europa's crust is 273K. We will examine various combinations of amounts and composition of any salts which might be present, and the effects they might have on any residual liquid.

(d) Fanale, F.P. et al. (1982). Seasonal carbon dioxide exchange between the regolith and atmosphere of Mars: Experimental and theoretical studies. *J. Geophys. Res.*, **87**, 10215-10225. Zent, A.P. and F.P. Fanale (1987). Thermodynamic State of SO<sub>2</sub> on Io's Surface. *J. Geophys. Res.*, **92**, 4953-4958.

## PROPOSAL SUMMARY SHEET--ABSTRACT

### PRINCIPAL INVESTIGATOR:

Dr. Jonathan Fink  
Department of Geology  
Arizona State University  
Tempe, Arizona 85287  
(602) 965-3195

**PROPOSAL TITLE:** Determining Lava Flow Composition from Morphologic and Structural Criteria

### ABSTRACT:

- a. Objective: To develop and evaluate morphologic and structural criteria for the remote determination of lava flow rheology and composition.
- b. Progress:(NAGW 529) (1) Developed laboratory technique for simulating thermal, dynamic, and morphologic aspects of lava flows with solid crusts, using polyethylene glycol injected into cold sucrose solution. (2) Conducted 77 laboratory experiments which demonstrated that lava flows exhibit a continuum of surface morphologies from flows with no crust, to flows with levees, surface folds, rift-like fractures, and pillows, depending on the relative rates of crust formation and spreading. (3) Completed an analysis of the convective cooling of viscous flows. (4) Calculated longitudinal profiles of apparent yield strength for flows on Olympus and Ascraeus Mons. (5) Measured thermal infra-red spectra of glassy and pumiceous rhyolite and dacite lava samples to determine the spectral effects of changes in silica content and vesicularity. (6) Mapped and characterized diagnostic structural and textural features on silicic lava flows and domes that could be used to constrain the compositions of remotely observed extrusions.
- c. Proposed work: (1) Conduct additional laboratory experiments designed to evaluate the role of strain rate in the formation of lava flow surface morphology. (2) Analytically calculate the rate of formation of cooled crusts on flows erupted under venusian and martian conditions, in order to predict morphologic characteristics of flows and volcanic constructs which may be observed in high resolution images from Magellan and Mars Observer missions. (3) Estimate topographic gradients of martian volcanoes by assuming that the rheologic profiles of their lava flows are similar to those determined for basalt flows in Hawaii. (4) Measure thermal IR spectra of glassy, pumiceous, and crystal-rich lavas of several compositions, to allow more accurate interpretation of TIMS images of terrestrial lavas, and future TES data from martian flows.
- d. Summary Bibliography: 1 book edited, 4 papers, 11 abstracts, 7 talks.

## PROPOSAL SUMMARY SHEET--ABSTRACT

### PRINCIPAL INVESTIGATOR:

Dr. Jonathan Fink  
Department of Geology  
Arizona State University  
Tempe, Arizona 85287  
(602) 965-3195

PROPOSAL TITLE: Rheology and Composition of Martian Mass Movement Deposits

### ABSTRACT:

- a. Objective: To develop structural criteria for evaluating the rheology of mass movement deposits with specific application to landslides in Valles Marineris and beneath the scarp of Olympus Mons, lobate debris aprons in the fretted terrain, and aureole deposits around Olympus Mons and Arsia Mons.
- b. Progress: (1) Mapped spacings of surface ridges and orientations of lineations on two lobes of the Olympus Mons Aureole, applied surface folding model, and concluded that ratios of ridge spacing to deposit thickness are consistent with acoustic fluidization model of Melosh, which may also account for extremely long runout distances. (2) Found through 139 laboratory experiments that the mobility of wet debris is reduced by the presence of clay minerals, contrary to what had been widely assumed previously. This result implies that extensive martian deposits attributed to lahars may have had a different origin, or may not have incorporated much regolith material, or may have come from clay-depleted source areas. (3) Continued analytical modeling of deformation in rockfall avalanche and landslide deposits, incorporating basal friction and purely plastic rheology.
- c. Proposed work: (1) Continue to map and classify surface structures on martian debris flow, rockfall avalanche, lobate debris apron and aureole deposits, identifying regularly spaced structures and those indicative of specific deposit rheologies. (2) Apply available fluid instability analyses to regularly spaced structures on martian deposits. (3) Perform photogeologic and field examination of selected terrestrial deposits to help calibrate analytical models. (4) Conduct new analyses more appropriate to the mapped and inferred structural relationships in martian deposits. (5) Continue laboratory investigation of debris mobility, using wider range of particle size distributions. (6) Interpret rheology, emplacement styles, and compositions for martian deposits.
- d. Summary Bibliography: 2 abstracts; 1 thesis; 2 talks; 2 papers in prep.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:

Dr. Richard G. French  
Department of Astronomy  
Whitin Observatory  
Wellesley College  
Wellesley, MA 02181  
(617) 235-0320 (x3747)  
rfrench@kepler.wellesley.edu

CO-INVESTIGATOR:

Dr. Mark Showalter

PROPOSAL TITLE:

Dynamics and Structure of Planetary Rings

ABSTRACT:

- (a) Objectives: To investigate the dynamics and structure of the narrow rings of Saturn and Uranus by observing upcoming stellar occultations, fitting existing Uranus occultation data with detailed kinematical models, and comparing theoretical models of ring width variations with observations.
- (b) Accomplishments: 1) Weak dynamical effects in Uranus ring system quantified; 2) Analysis of 1988 Uranus occultation observations of u1052; 3) Comparison of Voyager and Earth-based observations of Uranus upper stratosphere.
- (c) Proposed Work: 1) Identify weak dynamical effects in Uranus ring system using improved orbit model; 2) Observational tests of mechanisms to account for anomalous ring widths; 3) Search for faint rings and ring arcs in Uranus system using Voyager images and stellar occultation observations; 4) Observations of occultation of SAO 187255 by Saturn system and of Uranus ring occultations; 5) Investigation of edge features and structure of the  $\delta$  and  $\epsilon$  rings from Mt. Palomar occultation observations; and 6) Detailed inversion of Earth-based occultation observations of Uranus upper stratosphere, using information obtained from Voyager solar and stellar occultations.
- (d) Summary Bibliography: French et al. "Uranian Ring Orbits from Earth-Based and Voyager Occultation Observations" (1988). *Icarus* **73**, 349-378; Baron and French "The Oblateness of Uranus at the 1 Microbar Level" (1989) *Icarus* (in press); French, Nicholson, Porco, and Marouf, "Dynamics and Structure of the Uranian Rings" (1989). A chapter in *Uranus* (U. of Arizona Press).



## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Herbert Frey  
(Name, Address, Code 622/Geophysics Branch  
Telephone Number) Goddard Space Flight Center, Greenbelt MD 20771  
301-286-5450

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE: Major Resurfacing Events in Martian History

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a)Objectives: Use Neukum and Hiller technique and methods we have since derived from it to determine the number and ages of major resurfacing events, especially for early Mars, to map out extent of now-buried surfaces, to determine thickness of materials associated with these resurfacing events. To develop a stratigraphy based on resurfacing events.  
(b)Accomplishments: Completed study of resurfacing history of Tempe Terra and surroundings, including estimates of thickness of materials associated with the Lunae Planum Age and younger resurfacing events. Found the thickness of ridged plains and other materials associated with resurfacing in the Coprates region of Mars to be generally thinner than previously thought, though consistent with DeHon's estimates. Determined the age of apparently Noachian-age ridged plains to be essentially the same as for Lunae Planum. Remeasured craters in the Elysium-Amazonsis knobby terrain area and confirmed our earlier result of oldest age of knobby terrain like that of cratered terrain to the south.  
(c)This year: Examine effect of different production curves. Complete resurfacing study of Elysium-Amazonsis region. Study additional cases of Noachian age ridged plains. Determine whether old crater ages are really resurfacing ages. Determine oldest age of martian crust revealed by this technique. Investigate significance of resurfacing events older than LPA.  
(d)Publications: 3 oral presentations, 3 extended abstracts, 1 paper submitted for publication since July 1988.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Michael J. Gaffey, Geology Dept., West Hall  
(Name, Address, Telephone Number) Rensselaer Polytechnic Inst., Troy, NY 12181  
(518) 276-6300

**Co-INVESTIGATORS:**  
(Name Only)

Meteorite Spectroscopy and Characterization  
of Asteroid Surface Materials

**PROPOSAL TITLE:**

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a. Objectives: The goal of this work is an improved understanding of the nature and evolution of the early inner solar system. Asteroids are surviving in situ fragments from the accretionary and early post-accretionary period. Their characterizations provide information on early conditions and processes at particular heliocentric distances, and provide a spatial context or constraints for data and models derived from meteorite studies. Our work involves lithologic characterizations of asteroids from reflectance spectra, and laboratory spectral studies of meteorites to develop interpretive calibrations and methodologies.
- b. Accomplishments of past year: 1) Completed the initial survey of porphyrin features in reflectance spectra of meteoritic and terrestrial analogues to C-type asteroids, showing detection limits in the ppm range; 2) Showed that the proportion of planetesimals which underwent heating sufficient to produce melting has a linear decrease from 100% at 1.8AU to 0% at 3.5AU; 3) Written a current review of asteroid surface material characterizations and implications; and 4) Showed that a variety of phyllosilicate features are present in the spectra of certain low-albedo asteroids.
- c. Proposed Work: Asteroid rotational spectral analysis will include: (349) Dembowska [thermal history and achondritic affinities - preparation of publication]; (6) Hebe [surface mineralogy and thermal history - preparation of publication], and (1) Ceres [surface mineralogy and aqueous alteration]. Analysis of CCD spectra of low-albedo asteroids for phyllosilicate mineralogy. Laboratory studies will include: spectral effects of metamorphism and aqueous alteration of carbonaceous chondrites; and the spectral calibration of porphyrins and other organics in meteoritic assemblages.
- d. Recent Publications: Gaffey, M.J. (1988) Thermal history of the asteroid belt: Implications for accretion of the terrestrial planets. Lunar Planet. Sci. 369-370; Vilas, F. and M.J. Gaffey (1989) Weak  $\text{Fe}^{2+}$  -  $\text{Fe}^{3+}$  charge transfer absorption features seen in CM2 carbonaceous chondrites and narrowband reflectance spectra of primitive asteroids. Lunar Planet. Sci. XX, 1156-1157.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Robert W. Gaskell (tel. 818-354-2116)  
(Name, Address, Jet Propulsion Laboratory, M.S. 301/125L  
Telephone Number) 4800 Oak Grove Drive, Pasadena, CA 91109

Co-INVESTIGATORS: S. P. Synnott  
(Name Only) \_\_\_\_\_

PROPOSAL TITLE: Satellite Shape and Topography

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- (a) We shall find the shape and topography of satellites using Voyager images. The shape will suggest whether a tidally stressed satellite is in hydrostatic equilibrium and, if so, determine whether its interior is differentiated. Topographic results may provide insights into crustal geology and tidal dissipation mechanisms. Our techniques (Gaskell, 1988) have already yielded useful scientific results (Gaskell, et al, 1988), suggesting that Io is in hydrostatic equilibrium and that it is differentiated, possibly having an iron core about 800 km in radius. Furthermore, a fourfold rotational symmetry observed in the large-scale topography suggests that the heating of Io occurs primarily by tidal dissipation in a partially molten asthenosphere. There is some evidence, which is still being examined, that Io may have a differentiated crust, with large areas of low-density, isostatically compensated crustal material accounting for broad topographic highs.
- (b) Preliminary studies of Ariel suggest that it has a non-hydrostatic shape:  $a - c \approx 5$  km and  $b - c \approx 2$  km. We have developed a physical model for Voyager camera distortions with significant photometric implications (Gaskell, 1989). Further work on Io suggests that it may have a differentiated lithosphere (Ross, et al., 1989).
- (c) This investigation relies on the precise digital determination of control point locations in image space and the use of stereographic techniques to locate these points in the body fixed reference frame. We shall include digitally identified limb points in the study, providing both increased coverage and a check of our landmark techniques. Initial targets will be Io, Europa, Mimas, Enceladus, Miranda and Ariel. Mimas has been investigated independently using limb data (*Icarus* 73, 25-65), and will provide a valuable check of our control point techniques. The Io study will continue with the addition of more control points and limb data. Work on modeling of camera distortions and photometric corrections will be completed. We shall also find the Voyager 1 camera focal lengths. Ultimately, we will find shapes and for all satellites with sufficient stereographic coverage.
- (d) Summary bibliography  
Gaskell, R.W.: Digital identification of cartographic control points.  
*Photogrammetric Engineering and Remote Sensing* 54, 723-727, 1988.  
Gaskell, R.W.; Synnott, S.P.; McEwen, A.S.; and Schaber, G.G.: Large-Scale Topography of Io:  
Implications for Internal Structure and Heat Transfer. *Geophys. Res. Lett.* 15, 581-584, 1988.  
Gaskell, R.W.: Electronic distortions in the Voyager vidicon. JPL EM 314-459, 1989;  
*Photogrammetric Engineering and Remote Sensing*, in preparation.  
Ross, M.N.; Schubert, G.; Spohn, T.; and Gaskell, R.W.: Internal Structure of Io  
and the Global Distribution of its Topography. submitted to *Icarus*, 1989.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Name, Address,  
Telephone Number)

Jay D. Goguen  
4800 Oak Grove Drive, MS 183-501  
Pasadena, California 91109  
(818) 354-8748, (FTS) 792-8748

CO-INVESTIGATORS:

None.

TITLE:

A 'Dense Atmosphere' Model for  
Scattering from Planetary Regoliths

**ABSTRACT:** (Single-spaced, type within box below. Paragraphs numbered (a) through (d) should include: (a) brief statement of the overall objectives and justification of the work; (b) brief statement of the progress and accomplishments of the prior year, or "new proposal"; (c) brief listing of what will be done this year as well as how and why; and (d) summary bibliography):

**A. OBJECTIVES:** To develop improved models for the quantitative interpretation of spectrophotometry, bi-directional reflectance, and polarimetry of planetary regoliths in terms of the composition and size distribution of the regolith particles. A better model for light scattering in regoliths will also enable more accurate calculation of surface temperatures, the vertical deposition of heat important to solid-state greenhouse models, and exposure times for planning future spacecraft observations.

**B. PROGRESS:** New proposal.

**C. PROPOSED WORK:** For wavelengths in the range 0.3 to 5 micrometers: 1) Use Mie theory to survey the phase functions for size distributions of particles of various compositions for planetary regoliths. 2) Use the doubling method to rigorously calculate multiple scattering in an optically thick layer of these particles to generate a 'dense atmosphere' model for regolith scattering. 3) Study the breakdown of the independent scattering approximation and interparticle shadowing for a range of particle albedos and sizes by comparing 'dense atmosphere' models with measurements of laboratory samples of spheres of known sizes and compositions. 4) Determine particle size distributions and compositions that are consistent with existing photometry and polarimetry of planetary regoliths (e.g. Titania, Europa, the Moon). 5) Use the 'dense atmosphere' model evaluated at wavelengths lacking photometry and polarimetry to predict observable photometric and polarimetric characteristics to test the validity of the model and refine our knowledge of regolith physical properties.

**D. SUMMARY BIBLIOGRAPHY:** Goguen, J. D. et al. (1989), V-filter Photometry of Titania, Oberon, and Triton Icarus 77, 239-247.; Veverka, J. et al. (1988), Photometry and Polarimetry of Mercury, in Mercury (M. Mathews, ed.), U. Arizona Press, Tucson, pp. 37-58; Goguen, J. D., and W. M. Sinton (1985), Characterization of Io's Volcanic Activity by Infrared Polarimetry, Science 230, 65-69; Goguen, J. D. et al. (1988), Io Hot Spots: IR Photometry of Satellite Occultations, Icarus 76, 465-484.

## PROPOSAL SUMMARY

Principal Investigator: Matthew P. Golombek  
Jet Propulsion Laboratory  
Mail Stop 183-501  
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Title: TECTONICS OF PLANETARY STRUCTURES

a. Objectives: Develop models for the geometry, kinematics, and dynamics of planetary structural features. Estimate the lithospheric deformation and regional or planetary tectonic strain (expansion or contraction) from kinematic models. Use the characteristics and geometry of structural features as a clue to: 1) the mechanical behavior of shallow planetary crusts, 2) the lithospheric strength and failure characteristics at the time of their formation, and 3) early thermal profiles.

b. Progress: 1) Completed paper on the relative importance of faulting and folding in the formation of planetary wrinkle ridges. 2) Completed paper on subsurface structure and thermal gradients on Europa from lithosphere deformation models of observed tension cracks. 3) Published study of spectrophotometric measurements to understand the geologic evolution of Europa.

c. Proposed Work: 1) Collect photoclinometric data of wrinkle ridges on Mercury and Mars, and further develop kinematic models that include the subsurface structure and tectonic shortening across them to better constrain lithospheric deformation on planetary surfaces. 2) Reevaluate the geometry of the causative stress field around Tharsis, compare detailed structural mapping results with revised lithospheric deformation models for Tharsis, and evaluate the subsurface structure of grabens and pits around Alba Patera, based on their width, depth, size, spacing, and likely mechanical models. 3) Measure the brittle lithosphere thickness from simple grabens on Io to estimate heat flow in non hot spot country rock. 4) Map the sequence of groove formation around undeformed blocks of cratered terrain on Ganymede to assess any strike-slip displacements.

d. Summary Bibliography: Buratti, B., and Golombek, M., 1988, Geologic implications of spectrophotometric measurements of Europa: *Icarus*, v. 75, p. 437-449. Golombek, M. P., Plescia, J. B., and Franklin, B. J., in review, Faulting and folding in the formation of planetary wrinkle ridges: *Journal of Geophysical Research*, January 1989. Golombek, M. P., and Banerdt, W. B., in review, Constraints on the subsurface structure of Europa: *Icarus*, January 1989. Golombek, M., 1989, A review of extensional tectonic features on Mars (expanded abstract): Abstracts for MEVTV Workshop, *Tectonic Features on Mars*, Lunar and Planetary Institute, in press. Golombek, M., Suppe, J., Narr, W., Plescia, J., and Banerdt, B., 1989, Involvement of the lithosphere in the formation of wrinkle ridges on Mars (expanded abstract): Abstracts for MEVTV Workshop, *Tectonic Features on Mars*, Lunar and Planetary Institute, in press.

## PROPOSAL SUMMARY

### PRINCIPAL INVESTIGATOR:

James L. Gooding  
SN21/Planetary Science Branch  
NASA Lyndon B. Johnson Space Center  
Houston, Texas 77058  
FTS 525-5126 / (713) 483-5126

### TITLE:

Thermodynamics and Kinetics of  
Planetary Volatile/Regolith Interactions

### ABSTRACT:

**a. Objectives.** Quantitatively assess regolith interactions with volatile compounds as geologic processes on Mars, comets, and other low-temperature planetary bodies. Use differential scanning calorimetry (DSC) and evolved gas analysis (EGA) to measure phase stabilities and reaction rates for interactions of water and other volatiles with candidate regolith materials.

**b. Progress in FY1989.** (1) Experimentally determined that vacuum-weathered sulfur (prepared and proposed as analog material for Io by D. B. Nash) possesses an unusual phase composition. DSC data confirmed inferences previously made (by Nash) by visible and near-infrared spectrophotometry. Results included measured temperatures and enthalpies of phase changes in vacuum-weathered sulfur as evidence for its existence in highly polymerized form. (2) Served as lead author for the chapter on "Physical and chemical weathering" to appear in the book, *MARS* (H. H. Kieffer, B. M. Jakosky, and C. W. Snyder, Eds.), to be published by the University of Arizona Press. Co-authors were R. E. Arvidson and M. Yu. Zolotov.

**c. Proposed Work for FY1990.** (1) Determine stability ranges for water-substrate complexes formed by interaction of water with selected geologic substrates at low temperatures (100-300° K). Based on phenomena previously observed by DSC during freeze-thaw cycling of soils, palagonite tuff, palagonitic soil, and smectite substrates will be used to simulate complexation under Martian conditions. Carbonaceous chondrites will be used to simulate complexation under conditions that might apply to the Martian moons (Phobos and Deimos) or cometary nuclei. Results will identify proportions of water inventories that might be sequestered in forms with thermal stabilities intermediate between those of ice and structural or adsorbed water in hydrated minerals. (2) Determine stability of hydrogen peroxide,  $H_2O_2$ , with respect to catalytic decomposition or chemical reaction while in contact with Mars-analog materials, including palagonite- and smectite-bearing materials, sulfate and chloride salts. Emphasis will not be on formation of  $H_2O_2$  but on the kinetics of its decomposition under Martian conditions. Results will help constrain the survivability of  $H_2O_2$  as a major oxidant in models for surface chemistry on Mars. (3) Complete experimental determination of thermodynamic properties of sulfur evolved in vacuum as they might apply to surface materials on the Jovian satellite, Io (with D. B. Nash, JPL, as collaborator).

**d. Summary Bibliography (FY1989).** Nash D. B. and J. L. Gooding (1989) In *Lunar Planet. Sci. XX*, Lunar and Planetary Institute, Houston, 760-761.

**e. Personnel.** Principal Investigator (25% time) and one support-contractor scientist/engineer (20% time) at JSC.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Jonathan C. Gradie  
(Name, Address, Planetary Geosci. Div./HIG, Univ. of Hawaii,  
Telephone Number) 2525 Correa Rd., Honolulu, HI 97822, 808-948-6488

Co-INVESTIGATORS:  
(Name Only)

none

PROPOSAL TITLE: Physical Properties of Asteroid Family Members, NAGW 927

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

### ABSTRACT:

a) The main objectives of this proposal are: 1) to study and interpret the general characteristics of the albedos and diameters of 350 asteroids produced from 10 $\mu$ m and 20  $\mu$ m radiometry obtained at the NASA Infrared Telescope Facility ; (2) to study and interpret the albedos and diameters obtained for specific classes of asteroids from this survey, namely, asteroid families such as Eos, Themis, Koronis and Nysa, which may show diameter-albedo correlations related to regolith properties; 3) examine in detail individual high-albedo asteroids; and 4) provide a comprehensive interpretation of these thermal observations in the context of the overall compositional structure of the asteroid belt and the formation and evolution of the solar system.

b) Progress since August 1988 (submission of previous proposal): The discrepancy between the 10 $\mu$ m and 20  $\mu$ m albedos and diameters of asteroids determined from groundbased observations (this work) has been found in the IRAS data for asteroids as well (Lebofsky). The apparent cause appears to be the inadequate absolute calibration of the 10  $\mu$ m and 20  $\mu$ m photometric systems, not the result of the thermal model as we previously thought. The issue of correcting absolute calibration is the topic of a separate proposal. Although the results of this recalibration will affect some of the results of this study, we plan to continue our investigation of the relative differences among asteroid albedos.

c) Proposed research topics for the coming year include: 1) continued investigation of the systematic difference between model albedos (and diameters) obtained from 10  $\mu$ m and 20  $\mu$ m observations; 2) a study of the major, belt-wide, trends seen in the data; and 3) the analysis of the albedos and diameters in the Themis family.

d) Recent Publications: Gradie, J.C and E.F. Tedesco (1988), "Albedos and Diameters for 350 Asteroids from the IRTF 10 $\mu$ m and 20 $\mu$ m Radiometry Survey," BAAS, 20, 866; Gradie, *et al.*, 1989 "Distribution of Taxonomic Types and the Compositional Structure of the Asteroid Belt" *Asteroids II*, in press.

## PROPOSAL SUMMARY SHEET--ABSTRACT

### PRINCIPAL INVESTIGATOR:

Ronald Greeley  
Department of Geology  
Arizona State University  
Tempe, Arizona 85287-1404  
(602) 965-7045

### CO-INVESTIGATORS:

Lisa Gaddis  
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Timothy E. Townsend  
Department of Geology  
Arizona State University  
Tempe, Arizona 85287-1404  
(602) 965-4581

**PROPOSAL TITLE:** Geological Studies in Planetology

### ABSTRACT

**OBJECTIVE:** The goals of this investigation are: 1) To study aspects of remote sensing important for Planetary Geology, including determination of the utility of visible and near-infrared imaging data to assess the sources, transportation paths, and deposition sites of surficial materials (principally windblown sand) on planetary surfaces; in addition an assessment would be made of the strengths and limitations of using radar images to produce planetary geological maps in which radar constitutes the sole source of data. Both of these aspects of remote sensing are critical for the use and interpretation of existing and future data to be obtained for Mars and Venus. 2) The second task is to study volcanic geomorphology with the focus on a) the surface appearance of ash deposits degraded (principally) by wind, b) the morphology and morphometry of very fluid lava flows; the approach is to study terrestrial analogs, extrapolate the results to the martian environment, and analyze specific volcanic areas on Mars including highland patera. 3) The third task is to provide facility support for the ASU image processing system and the branch Space Photography Laboratory. 4) The fourth task is to provide service functions including publication of Impact Newsletter and coordination of the Planetary Geology Speakers Bureau.

### NEW PROPOSAL

**PROPOSED WORK:** First year: a) apply linear mixing models to TM data for the Kelso Dunes in conjunction with the Geology Remote Sensing Field Experiment (GRSFE), b) conduct field work in Kelso to obtain samples to test the model (in subsequent years the mixing model would be applied to higher spectral/spatial resolution data), c) conduct radar geologic mapping of the GRSFE test site, applying planetary geologic mapping principles, d) collect data on wind eroded volcanic ash deposits in an extension of work initiated in South America, e) collect data on extremely fluid lava flows such as komatiites on Earth to determine factors such as flow dimensions, the formation of surface features such as lava tubes and channels, etc., f) apply the results of the terrestrial analog work to the study of Mars (principally the highland paterae, such as Amphitrites Patera, g) continue image processing tasks and planetary geology support roles.

### REFERENCES:

- Blount, G., Smith, M.D., Adams, J.B., Greeley, R. and Christensen, P.R., Regional aeolian dynamics and sand mixing in the Gran Desierto: Evidence from Landsat Thematic mapper images. (Submitted, *J. Geophys. Res.*)  
Craddock, R.A. and Greeley, R., 1988, Thickness and volume of mare deposits in Tsiolkovsky, lunar farside, *Proc. Lunar Planet. Sci. Conf.*, 19, Cambridge Univ. Press, 331-337.  
Greeley, R., Christensen, P. and Carrasco, R., 1989, Shuttle radar images of wind streaks in the Altiplano, Bolivia. (In press, *Geology*.)  
Greeley, R. and Crown, D.A., 1989, Volcanic geology of Tyrrhena Patera, Mars. (Submitted, *J. Geophys. Res.*).  
Greeley, R. and Martel, L., 1988, Radar observation of basaltic lava flows, Craters of the Moon, Idaho, *Int'l. Jour. Rem. Sen.*, 9, 1071-1085.  
Spudis, P.D., Swann, G.A. and Greeley, R., 1988, The formation of Hadley Rille and implications for the geology of the Apollo 15 region, *Proc. Lunar Planet. Sci. Conf.*, Cambridge Univ. Press, 243-254.



## PROPOSAL SUMMARY SHEET--ABSTRACT

### PRINCIPAL INVESTIGATOR:

Ronald Greeley  
Department of Geology  
Arizona State University  
Tempe, Arizona 85287-1404  
(602) 965-7045

CO-INVESTIGATORS: Nicholas Lancaster

PROPOSAL TITLE: *Studies of Martian Aeolian Geology*

### ABSTRACT

**OBJECTIVE:** To assess the current and past aeolian regimes on Mars through studies of features such as albedo streaks and dunes and compare the results with runs from the atmospheric Global Circulation Model (GCM) for Mars.

**PROGRESS:** Data on martian bright streaks, dark streaks and dunes have been entered into the ASU Vax 11/750 system; the GCM has been run for "nominal" Mars conditions for one year in increments of  $L_S=60^\circ$ ; the Viking IRTM rock abundance model and results have been entered into the computer; and a "best fit" algorithm has been written to analyze the correlations. Preliminary analyses show a good correlation between bright streaks and zones of high wind surface shear stress for the southern hemisphere summer. The correlation with the "rock abundance" model suggests a sediment transport path from Chryse Planitia southward and then extending eastward along the equator and ending in the Hellas Basin. In addition, an estimate of the volume of sedimentary material in the north polar dunes (using a technique developed for dunes on Earth) yields a value of  $1158 \text{ km}^3$ .

**PROPOSED WORK:** a) Refine the GCM results to take threshold vs non-threshold conditions into account, b) refine the "best fit" algorithm to give weighting to the number of aeolian features occurring in each bin, c) analyze correlation on a regional and local scale, d) develop models of sediment "sources and sinks" and transport paths.

### PUBLICATIONS:

Comparison of martian aeolian features and results from the global circulation model; (Fourth International Mars Colloquium Tucson) 1989, 119-123, Greeley, R., Skyeck, A., and Pollack, J.B.

Martian aeolian processes, sediments, and features (manuscript, submitted to Mars volume for the Fourth International Mars Colloquium, Tucson) 1989, 39 p., Greeley, R., Lancaster, N., Lee, S. and Thomas, P.

The north polar sand seas: Preliminary estimates of sedimentary volume. Workshop on Dust on Mars III, Lunar and Planetary Institute, 1988, p. 18-20, Greeley, R. and Lancaster, N.

Sediment volumes in the north polar sands seas of Mars (submitted to Jour. Geophys. Res.), 1989, Lancaster, N. and Greeley, R.

## PROPOSAL SUMMARY SHEET--ABSTRACT

**PRINCIPAL INVESTIGATOR:** Ronald Greeley  
Department of Geology  
Arizona State University  
Tempe, Arizona 85287-1404  
(602) 965-7045

**SCIENTIFIC COLLABORATOR:** H.J. Melosh (Task 1)  
Planetary Science Department  
University of Arizona  
Tucson, AZ 85721  
(602) 621-2806

**PROPOSAL TITLE:** *GEOLOGICAL STUDIES OF OUTER PLANET SATELLITES*

### ABSTRACT

**OBJECTIVE:** This proposal has three principal objectives: a) to assess the potential for impact-generated antipodal disruptions on icy satellites using computer models and photogeology, b) to determine the origin(s) and evolution of ridge and trough terrains on icy satellites and assess the similarities and differences in the process(es) shaping the terrain, and c) conduct global geological mapping for Io and Callisto. Meeting these objectives will enable better definition of the surface evolution for many of the outer planet satellites through an understanding of the role of large impacts in antipodal surface disruption and the role of ridge and trough terrain formation on the evolution of icy satellites. Global geological maps of Io and Callisto will provide a framework for geological and geophysical studies and will be important bases for the forthcoming Galileo mission.

**PROGRESS:** a) More than 50 computer runs of large impacts have been made to explore different interior models and impact parameters. Photogeologic and topographic observations have been used to test and evaluate the models for the formation of ridge and trough terrain, b) the text and map for Io have been submitted to the USGS for review. Possible surface disruptions are being compared to observed surfaces on both icy and silicate bodies in order to constrain satellite interior models, c) photoclinometric profiles of ridge and trough terrains have been made for areas on Miranda. Geological mapping for Callisto was deferred until the third year.

**PROPOSED WORK:** a) Continue computer simulations of impacts into a wide variety of planetary objects; complete the comparison of the results with photogeological analyses of icy satellites, b) refine the classification of ridge and trough terrain and review models for the origin of the terrain, and c) continue review stage of the global geological map of Io; initiate geological mapping of Callisto.

### PUBLICATIONS:

Greeley, R., S.W. Lee, D.A. Crown, and N. Lancaster, Observations of industrial sulfur flows: Implications for Io, submitted to *Icarus*.

Greeley, R., D.A. Crown, R.A. Craddock, and G.G. Schaber, Geologic map of Io, 1:15,000,000, in review, *U. S. Geological Survey*.

Pappalardo, R., and R. Greeley, 1988, Ridge and trough terrain : A geomorphological approach, *Bull. Amer. Astro. Soc.*, 20, 874.

Pappalardo, R., and R. Greeley, 1989, Diapiric walls as a model for ridge and trough terrain on icy satellites, *Lunar Planet. Sci.*, XX, 820-821.

Watts, A., R. Greeley, and H.J. Melosh, 1989, Formation of antipodal terrains on icy satellites, *Lunar Planet. Sci.*, XX, 1183-1184.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:

Richard Greenberg  
Lunar and Planetary Laboratory  
University of Arizona  
Tucson, Arizona 85721  
(602) 621-6940

CO-INVESTIGATOR:

None

TITLE: Dynamical Evolution of the Galilean Satellites

### ABSTRACT:

(a) Objectives: To elucidate the complex interactions of dynamical and geophysical processes among the Galilean satellites, and their implications for long-term orbital, structural, and geological evolution. To understand the feedback of tidal processes into orbital and rotational motion. To apply these results to analogous cases in other satellite systems.

(b) Progress this Year: Progress includes study of the evidence for observable orbital acceleration of the Galilean satellites, with an implication that thermal flux from Io may be an order-of-magnitude greater than the average over the past 300 yr; preparation of a major review of knowledge and theory on the origin and evolution of Miranda; continued geophysical and geological modeling of Europa; and modelling of tidal dissipation in blocky satellites with application to the evolution of both Miranda and Enceladus.

(c) Proposed Research: Global stress analysis and the relation to tectonic processes will continue, including application motivated by Miranda to small satellites with lumpy density anomalies. Effect of density anomalies and blocky structure on rotation, orbits, and tidal heating will continue to be explored. Study of behavior in deep resonance will continue, including mapping evolutionary paths on the other side of exact commensurability by present analytical methods, and near exact commensurability by numerical integration. Effects of varying mean motion will be included.

(d) Summary Bibliography: Five papers, plus one presentation abstract.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Richard Greenberg  
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University of Arizona  
Tucson, Arizona 85721  
(602) 621-6940

CO-INVESTIGATOR: None

TITLE: Planet Formation and Evolution: Collisional and Dynamical Processes

### ABSTRACT:

(a) Objectives: The purpose of this research program is to understand how interrelated collisional and dynamical processes affected formation of the planets and their subsequent evolution. We are investigating the dominant processes of planetary accretion, including radial transport and low-velocity interactions, how they produced the observed planetary and satellite systems, including the cometary cloud and the Moon, and how these processes govern the evolution of planetary rings, the asteroid belt, and excavation and delivery of meteorites.

(b) Progress in Past Year: Studies of processes involved in the intermediate stage of planet growth have continued: Momentum and mass transport in a particle swarm is being studied with a new analytical approach that allows for realistic collisional processes and non-uniformity of the disk; Planetesimal behavior during slow, close gravitational encounters is now analytically derived stressing the important transition from a random-velocity to a keplerian domain. A new analytical procedure has been developed to test the statistical mechanics of close approaches. Critical invited reviews have been prepared on the delivery of asteroids and meteorites to the terrestrial planets, on dust bands, on orbital resonances, and on regoliths of small bodies.

(c) Proposed Research: Study of the intermediate stage of accretion will continue to determine the state of the system at the beginning of the final agglomeration into planets. Viscous radial transport theory will be extended to include gravitational encounters as well as realistic collisions and will be applied to planetesimals. Studies of low-velocity encounters will continue using a method that will permit construction of an algorithm to integrate these effects into planet-growth models. Research on meteorite origins and delivery processes and on asteroidal dust bands will continue on several specific tracks.

(d) Summary Bibliography: 7 papers and 7 abstracts of presentations.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Bradford H. Hager  
(Names, Address, Seismological Laboratory  
Telephone Number) California Institute of Technology  
Pasadena, CA 91125 818/356-6938

CO-INVESTIGATORS: None  
(Name Only)

TITLE: Convection in Venus: Observations, Models and  
Comparison with Earth

### ABSTRACT:

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**a. Objective:**

The main objective of the proposed work is to increase our understanding of mantle convection in Venus by comparing predictions of convection models with observations of topography, geoid anomalies, and state of stress. This comparison should place strong constraints on the mechanical and thermal structure of Venus. The study is motivated by the strong correlation between geoid and topography on Venus, which suggests that both are primarily the result of mantle convection, and by our success with dynamic models of Earth's geoid. Comparisons of the inferred structures of Venus's and Earth's mantles should provide valuable insights into the evolution of terrestrial planets.

**b. Accomplishments of prior "year"**

Accomplishments include examination of the effects of partial internal heating vs complete basal heating on plume structure, dynamic topography and geoid anomalies for axisymmetric convection. We have also developed a simple theoretical model that attributes the high topography of Ishtar Terra to crustal thickening driven by convective downwelling in the subjacent mantle. The pressure gradient caused by the thickened crust is balanced by basal tractions that increase with the average crustal thickness; there may be difficulty generating the high tractions required by thick-crust models. Finally, we have made preliminary models for partial convective support of Tharsis and Elysium that suggest that mantle convection on Mars also has observable consequences.

**c. Proposed Work**

Use a (vectorized) finite element code written with collaborators Kellogg, King and Raefsky to extend our models of convection to spherical axisymmetry with temperature and depth dependent convection. Write up Kiefer's PhD. thesis for publication. Investigate coupling of crustal deformation and mantle convection using King's vectorized finite element code.

**d. Publications:**

1. Kiefer, W. S. and B. H. Hager, The Role of Mantle Convection in the Formation of Highland Regions on Venus, **Lunar and Planetary Science**, **20**, 520-521, 1989.
2. Kiefer, W. S. and B. H. Hager, The Role of Mantle Convection in the Origin of the Tharsis and Elysium Provinces of Mars, MEVTV-LPI Workshop Technical Report, in press, 1989.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Bruce Hapke  
Dept. of Geology & Planetary Science  
University of Pittsburgh  
Pittsburgh, PA 15260  
(412) 624-8876

CO-INVESTIGATORS: None

PROPOSAL TITLE:  
Photometric Analyses of Spacecraft Planetary Images

### ABSTRACT:

- (a) Objectives of Proposed Work: Continue to investigate the nature and composition of planetary surfaces and atmospheres by quantitative analyses of images taken by spacecraft and of ground-based observations, with supporting observational, experimental and theoretical research.
- (b) Accomplishments of prior year: (1) Developed analytic model for albedo and phase function of light scattering by single particle. (2) Continued experimental study of light scattering by large, irregular particles. (3) Identified new major phenomenon contributing to opposition effect.
- (c) Research proposed for coming year: (1) Continue development of theory to further understand effects of thermal emission and polarization. (2) Continue study of light scattering by large, irregular particles. (3) Continue to use theory to analyze photometric data on solar system objects, concentrating on Europa.
- (d) Recent Publications: B. Hapke (1989), The Surface of Io: A New Model, Icarus, in press. D. Domingue & B. Hapke (1989), Fitting Theoretical Photometric Functions to Asteroid Phase Curves, Icarus, in press. B. Hapke & A. Williams (1988), Search for Anomalous Opposition Spike in Crystalline Powders, BAAS, 20: 808.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Alan W. Harris  
MS 183-501, Jet Propulsion Laboratory  
4800 Oak Grove Dr. Pasadena, CA 91109  
(818) 354-6741 (FTS) 792-6741

CO-INVESTIGATORS: None

PROPOSAL TITLE: Asteroid and Satellite Studies

### ABSTRACT:

a. Objective: Theoretical and observational studies of asteroids and planetary satellites are proposed with the general objective of understanding the origin and evolution of the planetary system.

b. Progress: In the last year, most effort has been expended toward publishing observational results from Table Mountain Observatory. 12 full papers are currently submitted or in press, and about a dozen papers at meetings have been presented since the last full proposal. Principal results include: 1) About 100 sets of asteroid phase data have been fit to the H-G magnitude system to derive mean slope parameters for each of the major taxonomic classes of asteroids. 2) The E class asteroids 44 Nysa and 64 Angelina were found to have nearly identical phase relations, exhibiting an "opposition spike" at phase angles under  $2^\circ$ , remarkably similar to that of Saturn's rings, but quite different from that of any other observed asteroid. 3) Several dark asteroids were found to show much less opposition brightening than expected. 4) Several new techniques of data analysis and reporting have been developed and implemented, including modeling of time variable extinction, Fourier analysis of lightcurves to construct composites and phase relations, and archiving of lightcurve data in machine readable form.

c. Proposed work: 1) Continue reductions of asteroid lightcurve data, concentrating on shape and pole studies, photometric functions (primarily high or low albedo asteroids at very low phase angles), collaborative observations with radar, IR, and occultation techniques, and earth-approaching asteroids; 2) Complete a paper summarizing the results of fitting the H-G magnitude relation to all available phase data in the literature, to define nominal values of the slope parameter for asteroids where it has not been observed, and to explore deviations of the function from observations, with the aim of updating the H-G function, and making physical interpretations of individual objects; 3) Continue a study of debris clouds about asteroids with numerical calculations.

d. Summary bibliography: 1) Harris, A.W., and J.W. Young (1989) Asteroid lightcurve observations from 1979-1981. *Icarus*, in press. 2) Harris, A.W., and 11 co-authors (1989) Photoelectric observations of asteroids 3, 24, 60, 261, and 863. *Icarus*, in press. 3) Harris, A.W., and D.F. Lupishko (1989) Photometric lightcurve observations and reduction techniques. In *Asteroids II* (R. Binzel, T. Gehrels, and M. Matthews, eds.) U. Ariz. Press, in press.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Name, Address,  
Telephone Number)

WILLIAM K. HARTMANN

Planetary Science Institute

2030 E. Speedway #201, Tucson, AZ 85719

(602) 881-0332

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE:

STUDIES OF INTENSE PLANETARY CRATERING AND ITS  
EFFECTS

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) This proposal requests a restart of a multi-year study of planetary cratering, terminated in 1988 due to lack of funding. The program concentrates on diverse phenomena associated with the early intense cratering of the solar system and heavily cratered surfaces.

b) This is a new start proposal for a three-year program at an annual level of \$26.9K, but recent progress is relevant. Progress in the last year involved studies with Dr. David Grinspoon (Univ. Ariz., now at NASA Ames) on early cratering of earth, and included delivery of abstracts and talks at the LPI-sponsored workshop on Origin of the Earth, at the AGU San Francisco meeting, at LPSC XIX and XX, and at a conference on early tectonics in Paris (an expenses-paid invited talk at no cost to the program), and partial completion of a MS for publication on this topic.

c) Proposed tasks are listed in a prioritized sequence: (1) completion and publication of work on primordial terrestrial cratering effects with Dr. Grinspoon, based on last year's work and his thesis; (2) If PHOBOS mission is successful, a study of lunar crater statistics in the diameter range 1 to 100 m. to provide independent background data that can be used by PHOBOS team for direct comparison with Phobos craters in that size range; (3) If PHOBOS mission is not successful, studies of crater densities in far side heavily cratered lunar areas, to test whether the Strom "lunar highlands" crater diameter distribution, used by the Voyager team as a fundamental calibration, is correct. My earlier studies suggest it is not.

d)

1. Hartmann, V. K. (1989) Phobos: Comparison of Small Craters on Phobos and the Moon. LPSC 20, abstracts.
2. Grinspoon, D.H. and V.K. Hartmann (1988a). Constraints on the Magnitude and Time Dependence of the Intense Early Bombardment. AGU Fall Meeting, abstracts.
3. Grinspoon, D.H. and V.K. Hartmann (1988b). Intense Early Bombardment and its Effects on Primordial Earth. Conference on Origin of the Earth, Milpitas, CA, abstracts.
4. Hartmann, V. K. (1988). Crater Saturation Equilibrium in the Solar System: New Evidence. LPSC 19 abstracts. p. 449.



## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Bernard Ray Hawke  
(Name, Address, Planetary Geosciences Div./HIG  
Telephone Number) University of Hawaii, Honolulu, 808-948-6488

Co-INVESTIGATORS: Thomas B. McCord  
(Name Only)

PROPOSAL TITLE: Remote Sensing and Geologic Studies of Planetary Crusts

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A. Objectives: The primary goal of this research is to provide a better understanding of planetary impact and volcanic processes, as well as the composition and evolutionary history of a variety of solar system objects including the Moon, Mars, Ganymede, Callisto, Mercury, and the asteroids through analysis and interpretation of spacecraft and earthbased imagery and remote sensing data.

B. Progress: The highlights are as follows: (1) a major study of lunar explosive volcanism was completed, (2) it was demonstrated that mafic geochemical anomalies on the east limb and farside of the Moon are found in regions which exhibit a high density of dark-haloed impact craters, (3) our spectral data rule out all previous hypotheses for the origin of the Reiner Gamma Fm. except cometary impact, (4) remote sensing and geologic studies of Rima Mozart, Rima Hyginus, and the Crüger crater region were completed, (5) final spectral results were presented for 29 Amphitrite and the Apollo asteroid 1984, KB, (6) spectral data for lunar impact basins were acquired and analyzed; pure anorthositic deposits were identified on Orientale and Nectaris basin rings, (7) definite or probable rotational spectral variations have been found associated with 16 asteroids, (8) albedo and spectral anomalies were identified and mapped on Ganymede, (9) Tycho crater excavated highlands material was found to be dominated by Ca-rich clinopyroxene; the dark halo contains abundant impact glass, (10) the results of remote sensing and geologic study of Imbrium basin were published, and (11) a major study of lunar sinuous rilles was conducted.

C. Proposed Work: (1) use Apollo orbital geochemistry data to investigate and characterize lunar basin deposit compositions, highland volcanic deposits, and early (>3.8 AE) mare basalts, (2) spectral studies of basin deposits, impact craters, lunar rays, and possible highlands volcanic deposits will be conducted to investigate crustal composition and impact processes, (3) continue studies of dark-haloed craters, as well as fresh, bright craters on Ganymede and Callisto, (4) continue efforts to measure rotational spectral variations on asteroids and to assess the implications for composition and surface processes, (5) continue spectral studies of unusual asteroid types and families, (6) complete our investigation of the deposits associated with large martian impact structures, (7) continue investigations of impact melt deposits associated with craters on the Moon, Mercury, and the Earth, and (8) continue studies of lunar pyroclastic deposits.

D. Summary Bibliography: See Progress Report.

## ABSTRACT SUMMARY SHEET

PRINCIPAL INVESTIGATOR: James W. Head

CO-INVESTIGATORS & SCIENTIFIC COLLABORATORS:

L. Wilson, L. S. Crumpler, S. Keddie, J. Burt, J. Aubele, S. Murchie, N. Efford

PROPOSAL TITLE: Surface Processes on Mars and Its Satellites

### ABSTRACT:

- a) **Objectives:** To gain further understanding of the major geological processes on Mars and its satellites through theoretical analysis and observations of volcanism and volcanic deposits on Mars, and the processes of low velocity cratering and devolatilization on the satellites.
- b) **Progress:** 1) Near completion of a general theoretical analysis of volcanism in the martian environment that will permit the addressing of a series of major volcanological and geological problems; 2) Beginning of the assessment of the nature and evolution of martian central volcanic edifices, including comparisons in style, space, and time; 3) Continuation of the analysis of the degradation of basaltic flows on Earth and the application of the interpretation of the origin of deposits on the martian surface, specifically at the Viking lander sites; 4) Progress on the study of internal and external processes on Phobos and Deimos with emphasis on the processes of low velocity impact cratering and devolatilization.
- c) **Proposed Work:** 1) Complete the general theoretical analysis of volcanism in the martian environment and address specific problems associated with plinian, strombolian, hawaiian, vulcanian, and effusive eruptions; 2) continuation of the assessment of the nature and evolution of martian central volcanic edifices, including comparisons in style, space, and time; 3) Completion of the analysis of the degradation of basaltic flows on Earth and the application of the interpretation of the origin of deposits on the martian surface, specifically at the Viking lander sites; 4) Complete preliminary study of internal and external processes on Phobos and Deimos with emphasis on the processes of low velocity impact cratering and devolatilization, and apply to specific features on the satellites.
- d) **Supplementary Bibliography:** Murchie, S.L. and Head, J.W. (1989) Morphologic classes of grooves on Phobos: submitted to *Geophysical Research Letters*; Wilson, L. and Head, J.W. (1989) Dynamics of groove formation on Phobos by ejecta from Stickney: *Lunar and Planetary Science XX*, 1211-1212; Aubele, J.C., Crumpler, L.S. and Elston, W.E. (1988) Vesicle zonation and vertical structure of basalt flows: *Journal of Volcanology and Geothermal Research*, 35, 349-374; Murchie, S.L., Head, J.W. and Efford, N.D. (1989) Morphologic classes of grooves on Phobos: *Lunar and Planetary Science XX*, 744-745; Aubele, J.C. and Crumpler, L.S. (1988) Small-scale surface characterization of Mars: *Abstracts with Programs*, 20, No. 7, A77.

## ABSTRACT SUMMARY SHEET

PRINCIPAL INVESTIGATOR: James W. Head III

### CO-INVESTIGATORS & SCIENTIFIC COLLABORATORS:

C. M. Pieters, A. T. Basilevsky, A. S. Selivanov, V. I. Moroz, J. B. Garvin, W. Patterson, D. Senske, D. B. Campbell, S. Frank, E. Stofan, R. Vorder Bruegge, D. Bindshadler, L. S. Crumpler, J. Harmon, J. Kliever

PROPOSAL TITLE: Planetary Data Analysis

### ABSTRACT:

**a) Objectives:** To analyze a range of planetary data from Earth-based observations, USSR spacecraft missions, and other sources, in order to accomplish the following objectives: 1) Familiarization and preliminary analysis; 2) Correlation with other data sets; 3) Make available to the US community; 4) To study a range of scientific problems.

**b) Progress:** 1) Publication of initial analysis of Venera lander color images and distribution of the data set to the U.S. community; 2) Preliminary mapping of Pioneer-Venus equatorial images and correlation with other data sets; 3) Completion of some mapping and preparation for data acquisition for new data sets from Arecibo; 4) Continuation of Venera 15/16 image data analysis; 5) Publication of analyses of Arecibo altimetry; 6) Acquisition of images and data reduction in preparation for analysis of Arecibo lunar images.

**c) Proposed Work:** 1) Analysis of time-varying phenomena on Venera lander images and acquisition of additional spectrophotometric data from Venera 11/12; 2) Correlation of Pioneer-Venus imaging data with other data sets; 3) Complete detailed data acquisition and reduction from the Arecibo Venus May/June/July opportunity; continue analysis of these data; 4) Analysis of general Venera geologic units, and several specific quadrangles; 5) Continuation of analysis of equatorial Arecibo altimetry into eastern Aphrodite and Phoebe Regio; 6) Mapping of at least two lunar regions with Arecibo data.

**d) Supplementary Bibliography:** (1) Bindshadler, D.L. and Head, J.W. (1989) Characterization of Venera 15/16 geologic units from Pioneer Venus reflectivity and roughness data: *Icarus*, 77, #1, 3-20. (2) Crumpler, L.S., Head, J.W. and Campbell, D.B. (1987) Regional linear cross-strike discontinuities in the western Aphrodite highlands, Venus: *Lunar and Planetary Science XVIII*, 215-216. (3) Bindshadler, D.L. and Head, J.W. (1988) Diffuse scattering of radar on the surface of Venus: Origin and implications for the distribution of soils: *Earth, Moon and Planets*, 42, No. 2, 133-149. (4) Campbell, D.B., Hine, A.A., Harmon, J.K., Senske, D.A., Vorder Bruegge, R.W., Fisher, P.C., Frank, S. and Head, J.W. (1989) New Arecibo high-resolution radar images of Venus: Preliminary interpretation: *Lunar and Planetary Science XX*, 142-143.

## ABSTRACT SUMMARY SHEET

PRINCIPAL INVESTIGATOR: James W. Head III

CO-INVESTIGATORS & SCIENTIFIC COLLABORATORS:

S. Murchie, J. Kliever, C. Sotin, L. Wilson, E. Parmentier

PROPOSAL TITLE: Geologic Processes on the Galilean Satellites

### ABSTRACT:

a) Objectives: 1) Geologic Mapping: Publication of a geologic map of a large portion of Ganymede (Jg4 quadrangle). 2) Tectonic Studies of Icy Satellites: Characterization and interpretation of different periods of tectonic deformation, with emphasis on relating Ganymede's surface features to internal processes and on comparative studies of different satellites. 3) Volcanic Studies of the Galilean Satellites: Investigation of possible roles of different volatiles in emplacement and evolution of volcanic materials.

b) Progress: 1) Further revisions of Jg4 map package. 2) Publication of papers on shear deformation, geologic history, and cratering of Ganymede; continuation of studies of global stratigraphy and dark terrain volcanism and tectonics; acceptance of theoretical paper on mantle convection. 3) Continuation of study of possible role of ammonia in Ganymede volcanism.

c) Proposed Work: 1) Final review of proof of quadrangle map. 2) Continuation of studies of global stratigraphy and dark terrain geology; documentation of spatial distribution and morphology of grooved terrain types; comparison of theoretical modeling with geological analyses. 3) Continuation of study of role of ammonia in emplacement and evolution of volcanic materials.

d) Summary Bibliography: Murchie, S. and Head, J. (1988) Possible breakup of dark terrain on Ganymede by large-scale shear faulting, *Journal of Geophysical Research*, 93, 8795-8824. Murchie, S., Head, J. and Plescia, J. (1989) The cratering record of Ganymede and Callisto: Evidence for the character of the crater-forming impactor population, *Lunar and Planetary Science XX*, 746-747. Murchie, S., Head, J. and Plescia, J. (1989) Crater densities and crater ages of different terrain types on Ganymede, submitted to *Icarus*. Murchie, S. (1989) The volcanic and tectonic history of Ganymede, *Lunar and Planetary Science XX*, 742-743.

PRINCIPAL INVESTIGATOR: James W. Head III

CO-INVESTIGATORS & SCIENTIFIC COLLABORATORS:

E. M. Parmentier, E. R. Stofan, L. S. Crumpler, D. Senske, C. Sotin, V. Kryuchkov, D. Campbell, S. Frank, R. Grimm, S. C. Solomon, R. Vorder Bruegge, T. Byrne, J. Aubele, A. Pronin, D. Bindshadler, A. Basilevsky, M. Kreslavsky, Yu. Shkuratov, S. Keddie, R. Fletcher

PROPOSAL TITLE: Geological Processes on Planets and Satellites: Tectonism

ABSTRACT:

**a) Objectives:** To understand processes of tectonic evolution and mechanisms of heat transfer on planets and satellites with emphasis on Venus.

**b) Progress:** 1) Completed initial study of rifting as a geologic process in the Beta Regio area; 2) Documented evidence for divergent plate boundary characteristics in the Aphrodite Terra region; 3) Continued documentation of convergence, compressional deformation, and the formation of orogenic belts in the Maxwell and Freyja Montes area of Ishtar Terra, and in ridge belts in the Venus plains; 4) Continued documentation of the characteristics of corona structures and continued development of models for their origin; 5) Continued documentation of the characteristics of parquet/tessera terrain, and continued development of models for its origin.

**c) Proposed Work:** 1) Extend study of rifting in the Beta Regio area east to Astoria, and south to Phoebe Regio; 2) Continue the documentation of evidence for divergent plate boundary characteristics in the Aphrodite Terra region, and assessment of characteristics of other parts of the equatorial highlands; 3) Continue documentation of convergence, compressional deformation, with emphasis on the evolution of orogenic belts in Ishtar Terra and their relationships, and in ridge belts in the Venus plains and their link to extensional deformation; 4) Continue documentation of the characteristics of corona structures for the area covered by Venera 15/16 and in detail for the region west of Ishtar Terra, and continued development of models for their origin; 5) Continue documentation of the characteristics of parquet/tessera terrain, and continue development of models for its origin.

**d) Supplementary Bibliography:** (1) Vorder Bruegge, R.W., Head, J.W. and Campbell, D.B. (1989) Orogeny and large-scale strike-slip faulting: Tectonic evolution of Maxwell Montes, Venus: submitted to *Journal of Geophysical Research*. (2) Vorder Bruegge, R.W. and Head, J.W. (1989) Fortuna Tessera, Venus: Evidence of horizontal convergence and crustal thickening: submitted to *Geophysical Research Letters*. (3) Stofan, E.R. and Head, J.W. (1989) Coronae of Mnemosyne Regio, Venus: Morphology and origin: submitted to *Icarus*. (4) Sotin, C., Senske, D.A., Head, J.W. and Parmentier, E.M. (1988) Terrestrial spreading centers under Venus conditions: Application to western Aphrodite Terra: submitted to *Earth and Planetary Science Letters*. (5) Head, J.W. and Crumpler, L.S. (1988) Divergent plate boundary characteristics in Aphrodite Terra, Venus: A test of some predictions: *Earth, Moon and Planets*, in press. (6) Stofan, E.R., Head, J.W., Campbell, D.B., Zisk, S.H., Bogomolov, A.F., Rzhiga, O.N., Basilevsky, A.T. and Armand, N. (1989) Geology of a rift zone on Venus: Beta Regio and Devana Chasma: *GSA Bulletin*, 101, 143-156.

## ABSTRACT SUMMARY SHEET

PRINCIPAL INVESTIGATOR: James W. Head

### CO-INVESTIGATORS & SCIENTIFIC COLLABORATORS:

L. Wilson, E. Parfitt, L. Crumpler, J. Aubele, S. Vergnolle, K. Magee Roberts, E. Stofan, E. Slyuta, A. Basilevsky, P. Hess

PROPOSAL TITLE: Geological Studies of Planets and Satellites: Planetary Volcanism

### ABSTRACT:

**a) Objectives:** To study the process of planetary volcanism from theoretical, observational, systems, and comparative planetological points of view.

**b) Progress:** 1) Preliminary assessment of the nature of dike systems feeding flank eruptions; 2) Preliminary assessment of the nature of shallow magma chambers below cinder cones and domes; 3) Analysis of the factors responsible for the development of pyroclastic eruptions and the characteristics of pyroclastic eruption types (Hawaiian, etc.); 4) Preliminary interpretation of the variables in pyroclastic eruptions and how these variations can be interpreted from the resulting facies and deposits; 5) Initial assessment of the role of gravity in planetary eruption characteristics; 6) Preliminary assessment of the characteristics of Venus plains and associated eruption conditions; 7) Initial assessment of Venus cone/dome fields and interpretation of eruption conditions; 8) Initial assessment of petrogenesis in Venus environments.

**c) Proposed Work:** 1) Completion of a model of the nature of dike systems feeding flank eruptions; 2) Pursue consequences of a model for the nature of shallow magma chambers below cinder cones and domes in Hawaii and application to other deposits; 3) Pursue consequences of the analysis of the factors responsible for the development of pyroclastic eruptions and the characteristics of pyroclastic eruption types (Hawaiian, etc.); application to the eruption sequence of Hawaiian rift eruptions; 4) Completion of a model for the interpretation of variables in pyroclastic eruptions and how these variations can be interpreted from the resulting facies and deposits; application to observations of deposits; 5) Completion of the assessment of the role of gravity in planetary eruption characteristics; preparation of manuscript for publication; 6) Continuation of the assessment of the characteristics of Venus plains and associated eruption conditions; completion of mapping of Lakshmi Planum and extension to other regions; 7) Completion of the initial assessment of Venus cone/dome fields and interpretation of eruption conditions; mapping of additional areas for continuation of assessment; 8) Continuation of analysis of petrogenetic processes in the Venus environment.

**d) Supplementary Bibliography:** (1) Wilson, L. and Head, J.W. (1988) Nature of local magma storage zones and geometry of conduit systems below basaltic eruption sites: Pu'u 'O'o, Kilauea, Hawaii example: *J. Geophys. Res.*, 93, B12, 14,785-14,792. (2) Head, J.W. and Wilson, L. (1988) Basaltic explosive eruptions: Influence of gas-release patterns and volume fluxes on near-vent dynamic morphology, and the formation of subsequent pyroclastic deposits (cinder cones, spatter cones, rootless flows, lava ponds and lava flows): submitted to *J. Volcanol. Geotherm. Res.* (3) Roberts, K.M. and Head, J.W. (1989) Lakshmi Planum volcanism: Style, origin and relation to other volcanic deposits on Venus: *Lunar and Planetary Science XX*, 910-911, and *Science Highlights Volume*, NASA TM, in press. (4) Aubele, J.C. (1989) Characteristics and geologic/terrain associations of small dome-like hills on Venus: *Lunar and Planetary Science XX*, 28-29, and *Science Highlights Volume*, NASA TM, in press. (5) Hess, P.C., Head, J.W. and Parmentier, E.M. (1989) Melting of Venusian mantle at spreading centers: *Lunar and Planetary Science XX*, 406-407.

## PROPOSAL SUMMARY AND ABSTRACT

PRINCIPAL INVESTIGATOR:

Keith A. Holsapple

Aeronautics and Astronautics, FS-10

University of Washington, Seattle, WA 98195

(206) 543-6198

CO-INVESTIGATORS:

None

TITLE:

FUNDAMENTAL STUDIES OF IMPACT MECHANICS IV

a. Objective: This is a continuation of research performed during this last several years, involving both theoretical and numerical studies of a variety of impact phenomena, including cratering, surface spall and catastrophic fragmentation. An important facet of the research is to continue to develop and apply scaling laws to bridge the gap between small-scale laboratory experiments and the planetary conditions of interest.

b. Progress: Much effort has been expended on the code calculation of impacts to focus on the near-surface phenomena. An very high-resolution calculation, with many tens of thousands of unknowns, has been run for a large-scale impact using an arbitrary Lagrangian-Eulerian finite element code. That calculation was performed on a Cray supercomputer with support furnished by NSF. Those calculations disagree with a recent theory of near-surface spall ejection mechanisms. In addition, significant features in the cratering flows and ejecta patterns have been found to result when one allows a sliding interface between the projectile and planetary surface. These features have not been previously studied, due to the inability of prior codes to model the sliding interface.

c. Proposed Work: The code calculations that have been accomplished required additional developments to more accurately follow the motions in the crater lip region. More effort on a general Lagrangian-Eulerian scheme of mesh mapping is proposed. A suite of calculations with parametric variations in impact conditions is proposed to clarify uncertainties and disputes about scaling aspects of cratering. More general models of fracture will be studied. The applications and development of scaling laws for impact phenomena will continue.

d. Summary Bibliography:

Housen, K.R. and K.A. Holsapple, "On the Fragmentation of Asteroids and Planetary Satellites", *Submitted for Publication*, 1988.

Holsapple, K.A. and K.Y. Choe, "Surface Spall in Large Impact Events", *Lunar and Planetary Science Xix* p 501, 1988.

Housen, K.R. and K.A. Holsapple, "Scaling Problems in Catastrophic Collisions", *Lunar and Planetary Science Xix* p 509, 1988.

Holsapple, K.A., "The Scaling of Impact Phenomenon", *Intl. J. Impact Engr.*, 5, 343-355, 1987.

Fujiwara, Cerroni, Davis, Di Martino, Holsapple, Housen and Ryan, "Experiments and Scaling Laws for Catastrophic Collisions", in *Asteroids II*, 1988.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:**  
(Name, Address,  
Telephone Number)

Lon L. Hood

Lunar & Planetary Lab.

University of Arizona, Tucson, AZ 85721

(602) 621-6936

**Co-INVESTIGATORS:**  
(Name Only)

**PROPOSAL TITLE:** Lunar Paleomagnetism & Magnetic Effects of Impact Processes

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a) The investigation is designed to increase our understanding of the origin of lunar paleomagnetism and the general nature of plasma, magnetic field, and remanent magnetization effects of large-scale impacts on planetary surfaces. The work will further constrain the origin of the Reiner Gamma swirls which have been suggested to be the product of either (i) relatively recent cometary impacts on the Moon; or (ii) deflection of the solar wind ion bombardment by locally strong crustal magnetic fields.
- b) During the past year, we have published results of a detailed study of the distribution and origin of the lunar swirls, including numerical calculations of the trajectories of simulated solar wind ions in model lunar magnetic anomaly fields to test the solar wind deflection model for the origin of the swirls. In addition, we have applied a 2-D hydrocode to construct a more quantitative model for the expansion and interaction with the Moon of the partially ionized vapor cloud produced in basin-forming events. Results for impact velocities of 15 to 20 km/sec showed that the cloud periphery converges in the zone antipodal to the impact point in a time of 400-500 seconds. This time interval is comparable to that required for compressional seismic waves to converge in the same zone.
- c) During the coming year, we plan to continue developing a full quantitative model for plasma production and magnetic field effects of large-scale hypervelocity impacts on the Moon. An initial calculation will be made of the compression of a spatially uniform ambient magnetic field in the zone antipodal to the impact point. In addition to effects on ambient fields, intrinsic fields generated in the impact plasma cloud by non-aligned thermal and electron density gradients will be calculated.
- d) Hood, L. and C. Williams, The lunar swirls: Distribution and possible origins, *Proc. Lunar Planet. Sci. Conf. 19th*, pp. 99-113, 1989.
- Lin, R.P., K.A. Anderson, and L. Hood, Lunar surface magnetic field concentrations antipodal to young large impact basins, *Icarus*, 74, 529-541, 1988.
- Hood, L., Magnetic field and remanent magnetization effects of basin-forming impacts on the Moon, *Geophys. Res. Lett.*, 14, 844-847, 1987.
- Hood, L.L. and Z. Huang, Effects on ambient magnetic fields and plasmas of the expanding vapor cloud produced in lunar basin-forming impacts, in *Lunar Planet. Sci. XX*, pp. 422-423, 1989.



## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Alan D. Howard  
(Name, Address, Department of Environmental Sciences  
Telephone Number) University of Virginia, Charlottesville, VA  
22903 (804) 924-0563

**Co-INVESTIGATORS:** George Hornberger  
(Name Only)

**PROPOSAL TITLE:**

GROUNDWATER AND PERMAFROST PROCESSES ON MARS

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) *Objectives:* The proposed research will develop quantitative models of groundwater flow on Mars and the interaction of that flow with surface processes, ground ice, and the regolith. Such flow-related processes have been important in redistributing water on Mars and have significantly affected surface landforms and the regolith. The flow models utilize a combination of regional and cross-sectional simulations. Effects that will be considered include recharge, confinement of flow beneath permafrost, geothermal processes, ice-injection features, tectonic effects, loading and unloading effects, and water-rock chemical interactions. Surface landforms influenced by groundwater flow processes include fluvial channels, chaotic terrain, fretted terrain, putative glaciers, and possible pseudo-volcanic landforms.

(b) *Research Progress:* Experiments and theoretical models have been developed of the evolution of scarps and valleys by the processes of groundwater sapping, scarp backwasting, and fluvial downcutting. Morphometric techniques have been developed to objectively characterize and compare scarp and valley landforms. The morphometric parameters are being used to intercompare the models, terrestrial landforms of diverse origin, and martian scarp and valley forms.

(c) *Proposed Research:* A two-dimensional finite-element global groundwater flow model will be developed to examine the spatial patterns of groundwater flow and relationships to flow-related landforms. Various parameter values and boundary condition scenarios will be examined. Studies will be initiated of landforms that may have resulted from interactions of artesian groundwater with ground ice, such as chaotic and fretted terrain and pseudo-volcanic landforms.

(d) *Summary Bibliography:*

Howard, A.D. and C.F. McLane, 1988, Erosion of cohesionless sediment by groundwater seepage: *Water Resources Research*, 24, 1659-74.  
Howard, A.D., Kochel, R.C., and H.E. Holt, 1988, Sapping Features of the Colorado Plateau: *NASA SP-491*, 108 p. (includes 3 chapters by the P.I.).

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Bruce M. Jakosky  
(Name, Address, Telephone Number) Laboratory for Atmospheric and Space Physics and  
Dept. of Geological Sciences. University of Colorado.  
Boulder, CO 80309-0392; Phone (303) 492-8004

**Co-INVESTIGATORS:**  
(Name Only)

**PROPOSAL TITLE:**

Remote Sensing of Mars

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a. We are trying to understand the global, regional, and local-scale behavior of the martian surface, and to infer the nature of ongoing geological processes which act on the near-surface layer. To do this, we are quantitatively examining both in-situ and remote-sensing observations of the surface; by synthesizing disparate data sets, we can better constrain surface properties and processes.
- b. During the past year, we have synthesized in-situ and remote-sensing observations of the martian surface, completed analysis of the geographic variability of surface physical properties, completed modelling of the bi-directional reflectance from planetary surfaces, and begun analysis of the infrared emission properties of the martian surface.
- c. During the coming year, we will improve our quantitative understanding of the martian surface properties by: completing our model of surface thermal emission properties; incorporating atmospheric effects into the determination of surface thermal inertia; and participating in the Geological Remote Sensing Field Experiment (GRSFE).
- d. Calvin, Jakosky, Christensen, A model of diffuse radar scattering from martian surface rocks, Icarus, 76, 513-524, 1988.
- Moore and Jakosky, Viking landing sites, remote sensing observations, and physical properties of martian surface materials, Icarus, in press.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Raymond Jeanloz, Professor  
(Name, Address, Department of Geology and Geophysics  
Telephone Number) University of California, Berkeley, CA 94720  
(415) 642-2639; 642-3993

Co-INVESTIGATORS:  
(Name Only)

Experimental Studies of Core/Mantle Volatile  
Equilibria and Global Differentiation

PROPOSAL TITLE:

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a. The proposed work involves application of the laser-heated diamond cell to carry out experiments pertaining to core formation, outgassing and thermal histories of terrestrial planets. Phase equilibria, synthesis of new phases and study of kinetic properties are conducted under calibrated P and T in the range 10 to 150 GPa and 1500 to 7000 K. Equilibria among core-forming metal (iron alloy), mantle minerals (silicates, oxides) and volatile constituents under conditions of planetary interiors receive particular emphasis.
- b. Renewal of NAGW-604.
- c. 1. Examine mantle (silicate/oxide)-core (iron alloy) equilibria at deep-interior-P/T conditions, including melting, reaction with interdiffusion, and partitioning of radiogenic elements K and U. 2. Measure the pressure-temperature-frequency dependence electrical conductivity of core, mantle and core-mantle boundary assemblages at deep mantle/core conditions. 3. Study H<sub>2</sub>O- and CO/CO<sub>2</sub>-silicate and H<sub>2</sub>O- and CO/CO<sub>2</sub>-iron alloy equilibria under P and T to establish planetary volatile budgets (H in Cores? H<sub>2</sub> in Deep Mantles?) and core formation processes.
- d. See Appendix.

Knittle, E., and R. Jeanloz, 1989, Simulating the core-mantle boundary: An experimental study of high-pressure reactions between silicates and liquid iron, *Geophys. Res. Lett.*, in press.  
Li, X., and R. Jeanloz, 1989, Laboratory studies of the electrical conductivity of silicate perovskite at high pressures and temperatures, *J. Geophys. Res.*, submitted.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Name, Address,  
Telephone Number)

R. E. Johnson

Department of Nuclear Engineering and  
Engineering Physics - (804)924-3244

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE:

Charged Particle Induced Alterations of Surfaces  
in the Outer Solar System

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) We propose calculating the effect of charged particle irradiation of surfaces of objects in the outer solar system. The intent is to describe the state of the irradiated surfaces in order to interpret remote sensing data of objects. This is needed to evaluate models for surface composition, rates for surface geology, and erosion rates for grains and ring particles.

b) We have calculated plasma bombardment profiles for satellites in a planetary magnetosphere with emphasis on Dione and Europa. These were used to compare to leading/trailing asymmetries. The first reflectance spectra of sulfur ion implantation into water ice were analyzed and compared to Europa reflectance (0.4 - 0.7  $\mu\text{m}$ ). The first laboratory data on  $\text{Na}_2\text{S}_x$  were used to consider the Matson et al. scenario for Na ejection at Io. Finally, our analysis of the satellite surfaces as sources for the heavy ion plasma at Saturn showed that additional sources are required inside the orbit of Enceladus.

c) We will calculate the effect on a regolith of grains of plasma bombardment in order to create reflectance spectra profiles at a number of objects. We will examine the effect of the plasma on surface transport on Io in order to examine lifetimes of bright spots, productions of dark regions, etc., will use recent Pluto data to consider radiation effects, and will begin to examine possible irradiation effects at Tritan.

d) Recent Papers

Analysis of Voyager Images of Europa: Plasma Bombardment Icarus 75  
(1988)

Magnetospheric Ion Bombardment Profiles of the Icy Satellites: Europa  
and Dione Icarus 76 (1988)

Application of Laboratory Data to the Sputtering of a Regolith Icarus 77  
(1989)

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Torrence V. Johnson  
(Names, Address, 4800 Oak Grove Drive, MS 183-501, Pasadena, CA 91109  
Telephone Number) (818) 354-2761

CO-INVESTIGATORS: Robert H. Brown, Dennis L. Matson and Jay Goguen  
(Name Only)

TITLE: MULTISPECTRAL ANALYSIS

ABSTRACT: (Single-spaced, type within box below. Paragraphs numbered (a) through (d) should include: (a) brief statement of the overall objectives and justification of the work; (b) brief statement of the progress and accomplishments of the prior year, or "new proposal"; (c) brief listing of what will be done this year, as well as how and why; and (d) summary bibliography):

A. OBJECTIVES: This research involves analysis of multispectral data and images from spacecraft and telescopes. Current thrust is analysis of multispectral global mosaics produced from Voyager observations of the Galilean, Saturnian, and Uranian satellites. Included are studies of the distribution of distinct spectral and compositional units on the satellites, and their relationship to: geologic features, ground-based spectral studies, and interactions with the Jovian magnetosphere. Integrated studies of Io, including Voyager and groundbased infrared data are arrived at understanding its volcanic nature and the distribution of volatile material on the surface. A search will be made for methane clathrate, ammonium hydroxide ice and carbon monoxide frost on icy satellites using telescopic data obtained under separate funding.

B. PROGRESS: Since the beginning of this task in 1982, progress has been made on characterizing Voyager multispectral data, including camera calibration. Recent work has focused on relating Voyager Io data to groundbased telescopic data to obtain information on hot spot distribution and heat flow and the distribution of temperature and SO<sub>2</sub> across the surface. Analysis of 1986 Io infrared data resulted in the discovery of a high temperature outburst with a model temperature higher than reasonable models for sulfur volcanism, providing the first direct evidence for a probable silicate eruption. Mutual satellite occultation data have also been analyzed and are providing new information on the location and characteristics of hot spots. A review chapter on Io's atmosphere for the book, Origin and Evolution of Planetary and Satellite Atmospheres was completed. Uranus satellite data analysis is continuing as well as analyses of Triton radiometric observations in support of the Voyager encounter in August 1989. The effects of solid state greenhouse on icy satellite surface thermophysics are also being studied.

C. PROPOSED WORK: During the coming year, we expect to: (1) continue analysis of icy satellite data in conjunction with USGS and UH, (2) analyze Voyager 2 data for Uranus satellites, (3) characterize Io's volcanic distribution and time variability, and (4) analyze spectrophotometry for Europa, Ganymede, Enceladus, Ariel and Titania and (5) analyze radiometric Triton data, (6) update to Voyager camera calibration.

D. SUMMARY BIBLIOGRAPHY: Multiple abstracts, 5 papers published (1988), 5 papers in press.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: William M. Kaula  
(Name, Address, Telephone Number) University of California, Los Angeles  
Department of Earth & Space Sciences  
405 Hilgard Avenue  
Los Angeles, CA 90024  
213-825-4363

CO-INVESTIGATOR: William I. Newman

PROPOSAL TITLE: Dynamics of the Origin of the Solar System

### ABSTRACT:

a. Objectives: 1) to determine the nature of heterogeneities occurring in the collapse of a solar-sized cloud, with emphasis on circumstances likely to lead to formation of a Jupiter; 2) to study the evolution of planetesimal swarms in the late stages of formation of the outer solar system, to understand the role of long-range effects on the accretion of Neptune and Uranus; 3) to explore the implications of hydromagnetic effects in kilogauss fields for collapse of the solar nebula.

b. Accomplishments of the prior year: 1) completion of the hydrodynamic collapse code, taking advantage of the Cray-XMP computer; 2) application of the direct N-body code to the Jupiter-Saturn zone, demonstrating that the absence of small bodies very likely arises from resonance instabilities; 3) development of a new N-body code more efficient for massless test-particles; 4) application of an Opik algorithm to the formation of the terrestrial planets, demonstrating that the differences in spin + satellite and apparent early heating of Earth and Venus plausibly arise from a penultimate stage of large planetesimals; 5) development of a model for hydromagnetic transfer of angular momentum in the nebula, consistent with the inference of kilogauss fields in T Tauri stars.

c. Plans for the coming year: 1) apply the hydrodynamic collapse code initially to clouds of low angular energy, and further develop criteria for collapse problem definition; 2) use the new test-particle code to search for stable niches and define resonance patterns throughout the outer solar system, so as to lay out an optimum strategy for the application of the massed N-body code to the late stages of formation of Uranus and Neptune; 3) refine the hydromagnetic model of angular momentum transfer in the nebula.

d. Recent relevant publications: Kaula, W. M. 1988: Planetesimal effects on planet orbits, spin, and heating, The Origin of the Earth, Lun. Plan. Inst., 44-45; Kaula, W. M. 1989: The earth as a planet, Quo Vadimus?, Garland et al, eds., American Geophysical Union, in press; Weibel, W.E. et al 1989: A computer search for stable orbits between Jupiter and Saturn, Icarus, submitted; Newman, W. I. 1989: Atomic and plasma processes in the early solar system: where has the angular momentum gone, Ap.J., submitted.

## PROPOSAL SUMMARY SHEET--ABSTRACT

### PRINCIPAL INVESTIGATOR:

Susan Werner Kieffer  
Department of Geology  
Arizona State University  
Tempe, AZ 85287-1404  
(602)-965-9011

### PROPOSAL TITLE: Fluid Dynamics of Multiphase Flow in Volcanic Environments on the Earth, Io, and Other Planets

#### ABSTRACT:

(a) Objective and justification: The objective of the proposed effort is to formulate numerical models for the flow of multiphase fluids through volcanic systems under planetary conditions where phase changes within the conduit and/or plume are important, and where transitions may occur from incompressible, subsonic to compressible, supersonic flow. Particular emphasis will be placed on comparing hydrothermal and volcanic processes on the Earth with active processes on Io, but consideration will also be given to eruptions on the Moon, Mars, Venus, and Europa. The basis for the proposed work is theory developed by the P.I. over the past two years for terrestrial hydrothermal systems that contain non-condensable gases, e.g.,  $\text{H}_2\text{O}$ - $\text{CO}_2$  geothermal systems, and the proposed work will extend this theory to aqueous solutions of S and  $\text{SO}_2$ . The proposed work will differ from past work on planetary volcanism in the different chemistry of materials considered, and in its focus on equations-of-state appropriate to the very low pressure and temperature conditions which eruption materials reach as they enter the low-pressure atmospheres, rather than on high-temperature silicate volcanism. The fluid dynamic model to be formulated will account for the following: (1) The complete equation-of-state of the fluid as it undergoes phase and component changes; (2) Mass, momentum, and energy conservation equations in conduits of variable geometry, including gas-expansion, gravity, heats of solution, friction, and work terms; and (3) Subsonic and supersonic flow regimes both within the lithospheric plumbing system and in an atmospheric plume. The justification for the work is that it will extend volcanic eruption models to pressures, temperatures and chemistries not yet quantitatively examined, and may provide suggestions for specific observations that can be made both by the Galileo spacecraft and by ground-based observers.

(b) New proposal. Relevant background work has been done regarding flow of pure S,  $\text{SO}_2$ ,  $\text{CO}_2$ , and  $\text{H}_2\text{O}$  from volcanoes into planetary atmospheres at different pressures (see ref. 1 and 2 below), and new experimental work has been done on the effect of density contrast between the volcanic plumes and atmosphere (see ref. 3 below).

(c) Proposed work, year 1: Equations of state of  $\text{H}_2\text{O}$ , S,  $\text{SO}_2$ , and  $\text{CO}_2$ , and aqueous solutions containing these compounds (e.g.,  $\text{H}_2\text{O}$ - $\text{CO}_2$ ;  $\text{H}_2\text{O}$ -S- $\text{SO}_2$ ....) with one or two dissolved cations ( $\text{Ca}^{++}$ ,  $\text{Si}^{+4}$ ), and simple magmas ( $\text{SiO}_2$ - $\text{H}_2\text{O}$ ;  $\text{NaAl}_3\text{SiO}_8$ - $\text{H}_2\text{O}$ ) will be formulated. These will be tabulated, fit with polynomials appropriate for use in the fluid dynamics model described, and used graphically to illustrate fluid flow and thermodynamic states in different parts of the volcanic plumbing system.

(d) Relevant bibliography: (1) Kieffer, S.W., Fluid dynamics and thermodynamics of ionian volcanism, Chapter 18, in The Satellites of Jupiter, ed. D. Morrison, 647-723, 1982. (2) Kieffer, S.W., Factors governing the structure of volcanic jets, in Explosive Volcanism: Inception, Evolution, and Hazards, report of the Nat. Acad. of Sci., Geoph. Study Comm. pp. 143-157, 1984. (3) Kieffer, S.W., and B. Sturtevant, Laboratory studies of volcanic jets, J. Geophys. Res. 89, 8253-8268, 1984.

## PROPOSAL SUMMARY

(Names, Address,  
Telephone Number)

Trude V.V. King  
USGS, MS 964, Box 25046 DFC, Denver, CO 80225  
(303) 236-1373; FTS 776-1373

CO-INVESTIGATORS:  
(Name Only)

R.N. Clark, D. Sherman

TITLE: Compositional Analysis of the Martian Surface

ABSTRACT: (Single-spaced, type within box below. Paragraphs numbered a. through d. should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal"; c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.):

a. Fine-grained materials cover a significant portion of the surface of Mars, however their compositions are not well-defined. Theoretical applications, direct sampling by the Viking landers and remote observations argue for the presence of high-Fe basalts and associated altered materials as the predominant mineral assemblages on the surface of Mars. The proposed work will more accurately determine the composition of these dark and light areas by using spectroscopy of mineral mixtures, based on laboratory experiments and theoretical considerations in the wavelength region from 0.2 to 200 $\mu$ m. Using these measurements it should be possible to distinguish the primary rock-forming silicates and their weathering products. Thus, rocks types and individual minerals can be identified.

b. Renewal proposal

c. The proposed work will incorporate the spectra (0.2-200 $\mu$ m) of standard laboratory mineral and rock samples in conjunction with theoretical mineral mixing models to more accurately determine the composition of the Martian surface. The laboratory data will be compared and contrasted to the reflectance spectra (0.35 to 2.5 $\mu$ m) of Mars obtained by Earthbased telescopic methods the Mariner 6 and 7 IRS instrument (2.0-14.0 $\mu$ m) and the Mariner 9 Infrared Interferometer Spectrometer (IRIS) data (~6.0-50 $\mu$ m). The spectra will be collected using a modified Beckman 5270 Spectrophotometer, a Nicolet 740 FTIR Spectrometer and a modified Mossbauer Spectrometer.  
d. King, T.V.V. and R.N. Clark, 1989, Spectral Characteristics of serpentines and chlorites using high resolution reflectance spectroscopy. *Jour. Geoph. Res.*, in review.

King, T.V.V. and W.I. Ridley, 1987, Relation of the spectroscopic reflectance of olivine to mineral chemistry and some remote sensing implications. *Jour. Geoph. Res.*, 92, 11,457-11,469.

Clark, R.N., R.B. Singer, G.A. Swayze, and A. Tokanaga, 1989, Discovery of Globally Distributed Scapolite on Mars. Fourth International Conference on Mars, abstracts, Tucson AZ, Jan. 10-13, 1989, pp 82-83  
Sherman, D.M. and T.D. Waite, 1985, Electronic spectra of Fe<sup>+3</sup> oxides and oxide hydroxides in the near-IR to near UV. *Amer. Minerl.*, 70.



## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Name, Address,  
Telephone Number)

Randolph L. Kirk  
2255 N. Gemini Dr., Flagstaff, AZ 86001  
602-527-7020; FTS 765-7020

Co-INVESTIGATORS:  
(Name Only)

Henry Moore

PROPOSAL TITLE:

Mars Surface Roughness From Two-Dimensional  
Photoclinometry

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objectives: To apply recently developed techniques for two-dimensional photoclinometry (PC) to Viking Orbiter image data to calculate digital topographic models for selected Martian sites to determine from these models the surface-roughness characteristics of these sites. These surface-roughness data will be used to (1) provide independent confirmation of the radar slope estimates, if possible, and estimate slopes in areas not probed by radar (with application to landing-site selection for future Mars missions); (2) investigate the variation of rms slope over well-defined horizontal scales in an attempt to explain the lack of wavelength dependence in the radar results; (3) quantify more subtle aspects of the surface roughness such as the shapes of slope probability distributions and the isotropy of slopes, and (4) relate the roughness properties to the geologic features in the images. Estimates of the surface roughness of Mars based on radar scattering properties (which are sensitive to the distribution of slopes  $\gtrsim$  a wavelength in extent, averaged over large areas of the planet) have proven difficult to relate to other properties. In contrast with the Martian data, the lunar radar-derived roughness estimates correlate strongly with roughness estimates from images, with geologic units, and with a wide variety of properties including thermal inertia, albedo, and age (Moore *et al.* 1980). Particularly perplexing is the lack of evidence for dependence of the radar-derived roughness on wavelength for most Martian areas studied. Such dependence (clearly seen for the Moon) would be expected on the basis of the simple arguments that slopes measured over shorter baselines normally exceed those on longer baselines and that different wavelengths are sensitive to slopes at different scales. On the basis of lunar experience, the range of baselines that best correlate with 13 to 70-cm radar data is readily resolvable in Viking images, giving hope that PC results may allow us to solve this problem.

b. Progress: In the 6 months since the proposal was funded, we have developed software for simulation of rough surfaces with known statistics (fractal, "Hagforsian," and Gaussian) and for estimation of roughness parameters from digital terrain models. We have begun investigating the reliability of PC roughness estimates. We have also begun selection of Viking Orbiter images for study, concentrating on areas covered by radar.

c. Work Plan FY90: (1) Complete PC roughness analysis of areas covered by radar. (2) Select and analyze additional images that extend the method to regions for which radar data are not available. (3) Correlate the derived roughness properties with local geology and compare radar-scattering behavior predicted from the topography with that observed (where available).

d. Relevant Bibliography: KIRK, R. L. (1984) A Finite Element Approach to Two-Dimensional Photoclinometry (abs.). *Bull. Amer. Astron. Soc.*, 16, 709. KIRK, R. L. (1987) A Fast Finite Element Algorithm for Two-Dimensional Photoclinometry. Part III, Ph.D. Thesis (unpubl.), Caltech, 165-258. MOORE, H. J. *et al.* (1980) Lunar Remote Sensing and Measurements. U.S. Geol. Surv. Prof. Paper 1046-B, 78 p.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Name, Address,  
Telephone Number)

Randolph L. Kirk

2255 N. Gemini Dr., Flagstaff, AZ 86001

602-527-7020; FTS 765-7020

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE:

Practical Two-Dimensional Radarclinometry  
and Photoclinometry

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a. Objectives and Justification: Photoclinometry (PC) and especially radarclinometry (RC) are potentially valuable tools for deriving topographic information that is unavailable by other methods and is useful in a wide variety of planetary geologic studies. Preliminary testing of a rapid finite element PC/RC algorithm has indicated that a simultaneous solution for the topography over a 200 by 200-pixel image can be obtained in a few tens of minutes (the computation time scales directly with the number of pixels) and has allowed identification of the most important obstacles to wide application of the method. I propose to (1) further develop the algorithm to address these obstacles, (2) make the PC/RC software available to the planetary community, (3) prepare for the clinometric extraction of high-resolution topography from Magellan images of Venus in 1991, and (4) use clinometrically derived topography to study several planetary geologic problems not addressable by current techniques. I will first implement well defined "fixes" to specific problems limiting the scope of the monoscopic clinometry algorithm, which uses one image and requires spatially uniform scattering properties. I will test the improved algorithm on a series of carefully chosen radar images (with varying degrees of ideality in terms of noise, backscatter variation, etc.) of known topography, and on simulated Magellan images synthesized from Pioneer Venus topography. I will also use it to study the morphology and mode of origin of grooved terrain on icy satellites. I will then develop related but more complex algorithms to address the problems of albedo variation and atmospheric effects (more significant for PC, especially when applied to Mars), by incorporation of *a priori* topographic information to improve the solution and constrain simultaneous fitting of an atmospheric model, and by simultaneous solution for albedo and topography from a pair of registered images. I will apply the new techniques to Mars to study the geology of the Valles Marineris interior deposits and of the polar layered terrains.
- b. Progress: New proposal (but see Introduction)
- c. Work Plan FY90: (1) Continue development of *a priori* constrained photoclinometry. (2) Use bispocopic and constrained photoclinometry to study the stratigraphy of Valles Marineris and of polar deposits on Mars.
- d. Relevant Bibliography: KIRK, R. L. (1984) A Finite Element Approach to Two-Dimensional Photoclinometry. *Bull. Amer. Astron. Soc.*, 16, 708. KIRK, R. L. (1987) A Fast Finite Element Algorithm for Two-Dimensional Photoclinometry. Part III, Ph.D. Thesis (unpubl.), Caltech, 165-258.

## SUMMARY

PRINCIPAL INVESTIGATOR: Paul D. Komar  
College of Oceanography  
Oregon State University  
Corvallis, Oregon 97331-5503  
(503) 754-2296

TITLE: Investigations of Techniques Applied to Hydrodynamic  
Interpretations of Floods

- (a) My research is focusing on methods for evaluating the hydraulics of floods based on erosional and depositional evidence, and on channel patterns. Three techniques are being investigated; flow-competence evaluations, analyses of the patterns and depths of scour around flow obstacles, and the patterns and scales of channel sinuosity. Such investigations will permit improved evaluations of flow stresses, velocities, depths and discharges of the floods that eroded the channels on Mars, and can similarly be applied to examine extreme floods that have occurred on Earth.
- (b) My work on flow competence is nearly complete, and the results are reported on in eight papers in refereed publications. The results also have been presented at meetings of the Geological Society of America, the British Geomorphological Research Group, and most recently as invited talks at the 1988 and 1989 meetings of the American Geophysical Union.
- (c) Additional work on flow competence remains to be completed, and this is expected to produce three or four additional publications. However, the focus of my research is now turning to an investigation of the patterns of scour around flow obstacles, such features being common in the Martian outflow channels due to flow around remnant blocks of chaotic terrain, resistant crater rims and bedrock projections. I am reviewing the relevant engineering literature which deals with scour around bridge piers as this provides quantitative data on the patterns and magnitudes of the scour as a function of flow hydraulics and obstacle shape. The main aspect of the investigation is a series of flume experiments which will further explore such relationships, and will directly examine scour patterns observed in Viking photographs of the outflow channels.
- (d) Analyses are also being undertaken of the sinuosity and meandering of terrestrial rivers and of Martian channels. The approach involves the combined use of spectral analyses and spacial variations of angular deviations from the channel's mean course. This work is exploratory, but it is anticipated that the analyses will demonstrate how channel patterns depend on the flow hydraulics, and in the case of bedrock streams, on the structural architecture of the underlying rocks.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Larry A. Lebofsky  
Associate Research Scientist  
Lunar and Planetary Laboratory  
University of Arizona  
Tucson, Arizona 85721  
602-621-6947

PROPOSAL TITLE: AN INFRARED REFLECTANCE STUDY OF  
LOW ALBEDO SURFACE CONSTITUENTS

### ABSTRACT:

a) We propose to expand upon our previous laboratory IR-reflectance studies of low-albedo materials. Our objective is to analyze our telescopic data obtained under separate funding, obtain spectra of laboratory analogs, and compare these spectra in order to determine the mineralogy of the asteroids. It has been shown that the asteroids were probably formed fairly close to their present locations and the majority may be relatively unaltered since their formation. Thus, studies of these primitive bodies is important to our understanding of the formation and evolution of the solar system. Our work is also directly applicable data analysis from spacecraft encounters with asteroids and other small bodies by missions such as Galileo, CRAF, and Phobos.

b) Even though we are in our third year of funding, this program has had funding in hand for just over a year since the July 1987 start date. During this period, we have obtained visual and infrared spectra of a suite of meteorites and low-albedo materials and have begun comparisons with telescopic observations. We have also made some preliminary attempts at obtaining spectra of cooled samples. c) During the next year, we propose to continue our laboratory studies. We are close to purchasing an environmental chamber for cooling our samples, in order to observe the effects on water in asteroidal clay minerals. At the same time, our observational studies of primitive asteroids are also expanding so we will have a much larger data base for analysis and comparison. Our primary goals are to: 1) analyze near IR (1.0 to 4.0  $\mu\text{m}$ ) spectra of asteroids obtained under separate NASA funding 2) compare these to our presently existing laboratory spectra of meteorites, meteorite analogs and other low-albedo materials 3) continue efforts to obtain spectra under low-temperature conditions with the system we are procuring under present yearfunding, and 4) conduct a literature search, reanalysis of our old data, and new reflectance studies of low-albedo candidate materials for comparison with unidentified spectral features in our existing spectra of outer belt and Trojan asteroids. d) Jones (1988), Lebofsky *et al.* (1989), Jones *et al.* (1989).

## PROPOSAL SUMMARY

Principal Investigator:

Steven W. Lee  
Laboratory for Atmospheric and Space Physics  
Campus Box 392  
University of Colorado  
Boulder, Colorado 80309  
Telephone: (303) 492-5348

Co-Investigator:

R. Todd Clancy

Scientific Collaborator:

Philip R. Christensen

Proposal Title:

Viking Photometric, Albedo, and Thermal Studies of Mars

Abstract:

a) This project is intended to improve our understanding of the physical nature of the martian surface. The goal is to determine the current sediment transport rates and directions in numerous regions, and to infer details of surface properties (mantling, roughness, texture) through photometric and mapping analyses of Viking Orbiter IRTM data. These details should provide new insight into the sedimentary processes currently affecting the martian surface, allow these processes to be related to those active over the longer term, and provide useful input to the design of observations to be made by the Mars Observer spacecraft.

b) During the previous year, software to access and analyze the necessary IRTM data sequences has been developed. This includes development of a model to correct for scattering from atmospheric dust, and the development of a nonlinear least squares fitting technique to fit various photometric functions to the IRTM sequences. To date, seven regions on Mars have been analyzed.

c) During the coming year, the remaining IRTM sequences will be analyzed. A more detailed atmospheric correction will be incorporated using a discrete ordinate radiative transfer code. For areas found to have distinct photometric signatures, regional mapping of albedo variations and thermal inertia will be used to infer details of regional sediment transport. The photometric functions, coupled with the thermal and albedo data, will allow relative differences in regional surface properties to be investigated and modeled.

d) Lee, S.W., P.C. Thomas, and J. Veverka, Wind streaks in Tharsis and Elysium: Implications for sediment transport by slope winds. *J. Geophys. Res.* 87, 10025-10042, 1982. Lee, S.W., Seasonal and Secular Variation of the Solis Lacus albedo feature: Relation to the martian dust-transport cycle, Submitted to *Icarus*, 1987. Clancy, R.T and G.E. Danielson, High resolution albedo measurements on Io from Voyager 1, *J. Geophys. Res.* 86, 8627-8634, 1981. Clancy, R.T., El Chichon and "mystery cloud" aerosols between 30 and 55 km: Global observations from the SME visible spectrometer, *Geophys. Res. Lett.* 13, 937-940, 1986.

## PROPOSAL SUMMARY -- ABSTRACT

PRINCIPAL INVESTIGATOR: Eugene H. Levy, Professor of Planetary Sciences  
Lunar and Planetary Laboratory  
University of Arizona  
Tucson, Arizona 85721  
(602) 621-6962

SCIENTIFIC COLLABORATORS: Dr. S. Araki, Dr. T. Stepinski, Mr. Stephen  
Pearce, Dr. Donald Shemansky

TITLE: Generation and Behavior of Solar-System Magnetic Fields

### ABSTRACT

- (a) Many solar-system objects possess magnetic fields generated by dynamos. The fields influence dynamical processes, and provide clues about planetary interiors. Evidence suggests an intense magnetic field present in the early solar-system nebula, which affected the solar system's formation. This research aims to elucidate the generation, behavior and influences of such solar-system magnetic fields.
- (b) Investigated generation and behavior of dynamo magnetic fields in the protoplanetary nebula and in planets; investigated angular momentum transport by dynamo magnetic fields in the protoplanetary nebula; began study of electrical conductivity of protoplanetary nebula gas.
- (c) We will continue calculations of the structures of protoplanetary nebula dynamo modes; we will make further use of supercomputers to carry out realistic model calculations, also to include effects on disk evolution. We will continue studies of nebular disk flares and nebular lightning, with emphasis on their possible role in chondrule formation and other transient disequilibrium phenomena that could have produced anomalous chemical states in meteorites. We plan to complete work on the generation of dynamo magnetic fields in the presence of imposed ambient fields, exploring the possibility that polarity asymmetries in Earth's magnetic field were induced in this way, and to develop some possibly new insights into the way in which planetary magnetic fields achieve dynamical equilibrium. We will continue theoretical work on the electrical conductivity of protoplanetary nebula gas.
- (d) 1988 "Generation of a Dynamo Magnetic Field in a Protoplanetary Accretion Disk" (T. Stepinski & E.H. Levy) *Astrophys. J.*, 331, 416.  
1989 "Magnetohydrodynamic Puzzles in the Protoplanetary Nebula", *Proceedings of the US-USSR Workshop on Planetary Science*, in press.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Jack Lissauer  
(Name, Address, ESS Dept., SUNY, Stony Brook, N.Y. 11794-2100  
Telephone Number) (516) 632-8225

Co-INVESTIGATORS: None  
(Name Only)

PROPOSAL TITLE:

DYNAMICAL PROBLEMS IN THE SOLAR SYSTEM

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a) Objectives: To develop a better understanding of several aspects of the origin and evolution of the solar system. The process of planetary accretion will be investigated in an effort to place constraints on the surface mass density distribution of the protoplanetary disk and the time scales of planetary growth. The ring systems of the giant planets will be studied to improve understanding of physical processes important in the solar nebula and other disk systems. The cratering record on some of the oldest surfaces in the solar system will be analyzed to learn about debris remaining at the end of the accretion epoch.
- (b) Progress: 1) Completed theoretical model and data analysis of the Titan nodal bending wave in Saturn's rings. 2) Wrote invited review paper on spiral waves in Saturn's rings. 3) Continued analysis of Voyager PPS uranian ring occultation data. 4) Wrote invited review paper on the arc rings of Neptune. 5) Proposed and developed a model to explain why the dust disk surrounding  $\beta$  Pictoris is much more luminous than those surrounding other nearby stars. 6) Continued investigating three-body planetary accretion rates in planetesimal disks with low random velocities. 7) Critically reviewed previous works on the possibilities of planet formation about stars of various masses. 8) Completed study of the bombardment history of the Saturn system using Voyager images of the cratering record. 9) Completed model of the changes in the rotation state of Halley's nucleus due to torques resulting from cometary activity.
- (c) Proposed Work: 1) Continue analysis of wave features observed in the Voyager radio occultation of Saturn's rings. 2) Derive best-fit optical depth estimates with error bars for Voyager PPS uranian ring data. Use these results to compute local eccentricity gradients for the  $\epsilon$  and  $\delta$  rings. 3) Compute protoplanet accretion rates in a gas-rich solar nebula. 4) Incorporate the effects of three-body scattering of planetesimals by protoplanets into a planetary accretion code. 5) Apply statistical tests developed in the study of the cratering record on Saturn's moons to other heavily cratered surfaces in the solar system.
- (d) Major Recent Publications: 1) Lissauer, Squyres and Hartmann (1988) "Bombardment History of the Saturn System" *J. Geophys. Res.*, **93**, 13,776. 2) Lissauer and Griffith (1989) "Erosion of Circumstellar disks by Interstellar Dust" *Astrophys. J.*, in press.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:**

(Name, Address,  
Telephone Number)

Baerbel K. Lucchitta

U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff,  
(602) 527-7176; FTS 765-7176  
AZ 86001

**Co-INVESTIGATORS:**  
(Name Only)

**PROPOSAL TITLE:**

Structure of the Valles Marineris

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

Objectives: The objective of the study is to contribute to an understanding of the origin and evolution of the Valles Marineris troughs by conducting a detailed analysis of structures within the troughs and on the nearby plateaus. The study will shed light on such questions as (1) the time of opening of the troughs and the influence of regional stress systems on their formation and evolution; (2) the relative importance of tectonic movement, surficial collapse, and erosional widening; and (3) the relative merits of models of origin involving either withdrawal of material at depth and collapse or plate-tectonic style rifting. The study will be accomplished by (1) conducting an inventory of all structures inside the troughs; (2) determining the time sequence of the structures, where possible; (3) relating the occurrence of structures to regional stress systems; (4) mapping dips of beds and fault planes; (5) investigating whether the transition from chain craters to narrow troughs to major troughs is a continuum or whether morphologic thresholds exist; (6) calculating volumes from digitized maps; and (7) comparing the troughs with terrestrial deep grabens formed by either surficial collapse or continental rifting.

Progress: New proposal.

Anticipated work: In the first year base materials will be acquired. All structures (faults, ridges, lineations, grabens, tilted beds) inside the Valles Marineris will be identified, mapped, and classified. We will obtain morphometric parameters (widths, depths) of chain craters, coalesced pits and troughs. We will also begin a study of fault-plane attitudes and terrestrial analogs.

Bibliography:

- Lucchitta, B.K., 1987, Recent mafic volcanism on Mars: *Science*, v. 235, p. 565-567.  
Lucchitta, B.K., 1987, Valles Marineris, Mars: Wet debris flows and ground ice: *Icarus*, v. 72, p. 411-429.  
Lucchitta, B.K., 1987, History of Valles Marineris (abs.), in *Lunar and Planetary Science 18*, Lunar and Planetary Institute, p. 572-573.



## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Paul G. Lucey  
(Name, Address, Planetary Geosciences Div./HIG, Univ. of  
Telephone Number) HI, 2525 Correa Rd., Honolulu, HI 96822, 808-948-6488

Co-INVESTIGATORS:  
(Name Only)

None

PROPOSAL TITLE:

Mineralogical Mapping of the Lunar Surface

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) This is a continuation proposal for the study of the composition and evolution of the lunar crust utilizing new remote sensing data collected under separate funding at Mauna Kea Observatory including imaging spectroscopy and mid-infrared spectroscopy. Imaging spectroscopy provides contiguous spectral coverage at 1% spectral resolution in the near-infrared for large portions of the nearside. The mid-IR provides crucial data on feldspar abundance difficult to obtain with the near-IR. These techniques will allow the accurate characterization of lunar rock types and their distributions for large portions of the lunar nearside.

b) The previous year saw the successful calibration of the imaging spectroscopy data and successful application of the mid-IR to determining lunar rock types in mare and highland areas.

c) This year will be spent analyzing the imaging spectroscopy data using spectral mixing models based on the work of Bruce Hapke. These models will be applied in a manner analogous to those applied to orbital geochemistry data to produce maps of mineral and rock type abundance.

d) Lucey, P.G., and B.R. Hawke, Imaging spectroscopy of the Central Highlands from .7 to 1.00 microns, *Lunar and Planet. Sci. Conf. XX*, 592-593 (1989), and Lucey, P.G., J. Granahan, M.L. Nelson, and B.R. Hawke, A spectral mixing model approach to the analysis of the spectra of lunar soils, *Lunar and Planet Sci Conf. XX*, 600-601 (1989).

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Jonathan I. Lunine  
(Name, Address, Lunar and Planetary Lab, Univ. of Arizona  
Telephone Number) Tucson, AZ 85721  
(602) 621-2789

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE: Theoretical Studies of Volatile Processes in  
the Atmospheres and Surfaces of Outer Solar System Bodies

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objectives: Investigate the role of volatile materials and processes in determining the present surfaces, atmospheres and evolution of outer solar system satellites and Pluto/Charon. Infer the composition of volatile molecular species on outer solar system bodies from spacecraft and ground-based data; use these to constrain chemical/physical models of their origin.  
(b) Progress: (1) Stellar occultation data on Pluto was interpreted in terms of an atmospheric thermal model and used to infer the presence of a gas heavier than methane, possibly carbon monoxide. (2) A model for Triton's atmosphere and aerosol haze was developed to assess the scattering of sunlight and visible optical depth to Triton's surface as a function of season. (3) The coupled evolution of Titan's hydrocarbon ocean and atmosphere was modeled using both grey and non-grey radiative transfer codes, providing a boundary condition for early evolution models. (4) The infrared signature of silicate flow hot spots on Io in the 1985 mutual events data was simulated. (5) The rheology of ammonia-water liquids was investigated experimentally and theoretically; evidence for glass formation was found. (6) Data on molecular abundances in comet Halley were used to constrain physical and chemical models of solid body formation in the outer solar system.  
(c) Proposed Work for this Year: (1) Use Voyager data to constrain parameters in the atmosphere-surface model of Triton now under construction; begin studies of seasonal and long-term evolution of Triton's surface and atmosphere using the model. (2) Begin construction of detailed models of the formation and early history of Titan, with emphasis on the interaction of surface/interior processes and atmospheric evolution. (3) Investigate plausible surface/interior processes on Pluto which could supply CO or N<sub>2</sub> to the atmosphere against escape processes. (4) Use individual IRIS observations of Loki on Io to derive some spatially resolved temperatures.  
(d) Sample references: J.I. Lunine, 1989, Icarus, in press; R.V. Yelle and J.I. Lunine, Nature, in press.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Michael C. Malin  
(Name, Address, Department of Geology  
Telephone Number) Arizona State University, Tempe, AZ 85287-1404  
(602) 965-4335, (602) 965-5081

**Co-INVESTIGATORS:**  
(Name Only)

Planetary Geomorphology

**PROPOSAL TITLE:**

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a. Objectives: to develop/apply quantitative techniques to the study of geomorphic processes. Specifically, to complete pre-Magellan studies of the tectonic history of Venus, to continue and expand laboratory measurements of ice/silicate mixtures under simulated martian conditions, to examine and quantify the nature of transverse hillslope evolution on Earth and Mars, and to examine mechanisms that create and transport coarse sediments on Mars.
- b. Progress: 1) analyses of rock populations created by catastrophic floods, volcanic explosions, and rockfalls provided insight into the use of very coarse debris to remotely distinguish these processes; 2) completed study of heavily cratered terrain in northeastern Arabia indicated substantial deposits of semi-indurated, plains-forming material draped over pre-existing topography, that have experienced a diverse and extensive erosional history; 3) analysis of Venera and Pioneer Venus data in collaboration with Dr. M. Markov (USSR Acad. Sci. Geologic Institute) and Prof. R. Phillips (SMU) continued; 4) initial runs of granular ices under simulated martian conditions showed the potential for sensitive study of vapor transport mechanisms in stable and unstable atmospheres.
- c. This Year: 1) complete the collaborative work with Phillips on Venus tectonics; 2) continue laboratory study of ice/silicate mixtures under martian conditions, and explore other thermophysical relationships using the environmental simulator; 4) continue analysis of boulder populations as indicators of geologic process; 5) initiate comprehensive study of transverse hillslope evolution on Earth and Mars.
- d. Summary Bibliography:  
Malin, M. C., 1988, Abrasion in ice-free areas of southern Victoria Land, Antarctica: Antarctic Journal of the United States 22(5), 38.  
Kelley, A. D., Malin, M. C., and Nielson, G. M., 1988, Terrain simulation using a model of stream erosion: Computer Graphics 22(4), 263-268.  
Eppler, D. B. and Malin, M. C., 1989, The May 1915 eruptions of Lassen Peak, California, I: Characteristics of events on 19 May: in Volcanic Hazards: Assessment and Monitoring, J. Latter (ed.) (Springer-Verlag, Berlin), 180-200.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Name, Address,  
Telephone Number)

Ho-kwang Mao

Geophysical Laboratory

2801 Upton St., N. W.

Washington, D. C. 20008

Peter M. Bell

Russell J. Hemley

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE: High-Pressure Studies of Planetary Gases and Ices (Second Year)

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objective: We propose a systematic study of the high-pressure properties of planetary gases ( $H_2$ ,  $D_2$ , HD, He, and  $H_2$ -He mixtures), ices ( $H_2O$ ,  $CH_4$ ,  $NH_3$ , CO,  $N_2$ ,  $CO_2$ , Ne, and binary mixtures of  $H_2O$ ,  $CH_4$ , and  $NH_3$ ), and multicomponent mixture of ices in  $H_2$ -He, to 300 GPa (3.0 Mbar) and 77-800 K using recently developed synchrotron x-ray and spectroscopic techniques and theoretical calculations. The results will be used to constrain models of Jovian planets.

b. Progress: Since the submission of the original proposal in July 1988, the maximum calibrated pressure has been increased from 180 GPa to 300 GPa. Optical properties of solid hydrogen were studied to pressures above 250 GPa at 77 K. The data were consistent with pressure-induced metallization of molecular hydrogen by band- overlap of an indirect gap. New high-pressure transformations between crystalline and amorphous ice were determined. Dramatic change in optical spectra of type Ia diamond were observed at high stresses up to 300 GPa. A superconducting wiggler beamline dedicated for high-pressure diamond-cell experimentation has been constructed at NSLS. Phase stabilities and equations of state of oxides, silicates and iron alloys have been studied systematically with x-ray diffraction up to 300 GPa. The results were used for modelling the rocky mantle and metallic core of the Earth and planets.

c. Proposed work for this year: (1) Single-crystal x-ray diffraction of He and  $H_2$ -He mixtures up to 50 GPa, 77-500 K. (2) Phase transitions and EOS of one-component planetary gas or ice up to 300 GPa, 77-800 K with polycrystalline EDX technique and Raman, fluorescence, absorption, and reflectance spectroscopies. (3) Theoretical calculations to be tested against the experimental results. (4) Working models of the interiors of Jovian planets based on the new results. (5). Extending the experimental  $P$ - $T$  capabilities.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Terry Z. Martin, Jet Propulsion Laboratory  
(Name, address, tel. no.) 4800 Oak Grove Dr., Pasadena, CA 91109

(818) 354-2178 (FTS) 792-2178

Dr. Ted L. Roush

CO-INVESTIGATORS:  
(Name Only)

Dr. James B. Pollack

TITLE: MINERALOGY OF THE MARTIAN SURFACE FROM MARINER 6/7 INFRARED SPECTROMETER  
DATA

ABSTRACT (Single-spaced, type within box below. Include: a. Brief statement of the overall objectives and justification of the work; b. Brief statement of the accomplishments of the prior year, or "new proposal"; c. Brief listing of what will be done this year as well as how and why; and d. One or two of your recent publications relevant to the proposed work.):

- a. Recent work to restore the Mariner 6/7 IR Spectrometer data set has created an opportunity to expand knowledge of the state of the Mars surface. It is proposed that these data be analyzed to extract information about the presence and nature of mineral species, focussing on their hydration state and the presence of various salts.
- b. New task
- c. The Mariner 6 and 7 IRS data are the only spacecraft spectral data for Mars between 2 and 5 $\mu$ m, and the best available in the 5-10 $\mu$ m range; the Mariner 9 IRIS data had poor signal:noise in this range with the exception of a few spectra obtained late in the mission when dust loading in the atmosphere was reduced. It is now possible for the first time to produce radiance spectra for the IRS data set, and thereby compare the data with atmospheric synthetic spectra. Removal of atmospheric effects makes possible assessment of the presence of minor features due to surface components; among possible vibrational fundamentals are those of water at 3 and 6 $\mu$ m, and carbonates, sulfates, and nitrates.
- d. "Data set restoration: the Mariner 6/7 Infrared Spectrometer", Bulletin of the AAS vol. 17, 723 (1985).  
"Airborne observations of Mars' thermal IR spectrum: Evidence for sulfates, carbonates, and hydrates", J. Pollack, B. Dalton, T. Roush, C. Stoker, F. Witteborn, and J. Bregman, presented at 4th International Conf. on Mars, Tucson, Jan. 10-13, 1989.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dennis L. Matson  
(Name, Address, Telephone Number) ~~Jet Propulsion Laboratory, 183-501~~  
~~Pasadena, California 91109~~  
~~(818) 354-2984, PTS 792-2984~~

Co-INVESTIGATORS:  
(Name Only) ~~Torrence V. Johnson, Glenn J. Veeder~~  
~~Robert H. Brown, Jay Goguen~~

PROPOSAL TITLE: ~~Surface Chemistry and Geophysics~~

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- A. OBJECTIVES:** To carry out investigations of the physical chemistry, composition and geophysics of satellites in the solar system. Emphasis is given to work which, in addition to yielding significant scientific results, gives information useful in planning measurements to be made by the Galileo and Cassini missions.
- B. PROGRESS:** We saw the eruption of a high-temperature magma on Io. It's 900 K temperature was far too hot for any sulfur phase and we suggest that it may be a silicate melt. In the 1st of a series of Io occultation papers we discusses this new approach. Several new hot spots were found and the location and temperature of Loki measured. Our 2nd solid-state greenhouse paper appeared, reporting subsurface temperature distributions under a variety of assumptions. Temperatures for bright satellites are likely to be higher than previously thought. A study of the distribution, abundance and stability of SO<sub>2</sub> on Io's surface was published.
- C. PROPOSED WORK:** Io hot spot work will continue with analysis of the existing database and preparation for upcoming occultations. A major effort will be made to understand Io's polar units which may contain H<sub>2</sub>S frost. Three papers in preparation will be submitted for publication.
- D. SUMMARY BIBLIOGRAPHY:** Io Hot Spots: Infrared Photometry of Satellite Occultations, by J. D. Goguen, et al., *Icarus*, 76, 465 (1988). \*Solid-State Greenhouses and Their Implications for Icy Satellites, by D. L. Matson and R. H. Brown, *Icarus* 77, 67 (1989). \*Io: Evidence for Silicate Volcanism in 1986, by T. V. Johnson et al., *Science* 242, 1280 (1988). \*The Global Distribution, Abundance, and Stability of SO<sub>2</sub> on Io, by A. S. O. McEwen, et al., *Icarus* 75, 450 (1988). Plus 7 published abstracts.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Ted A. Maxwell  
(Name, Address, NASM 3101, Smithsonian Institution  
Telephone Number) Washington, D. C. 20560  
202 357 1424  
Thomas R. Watters

Co-INVESTIGATORS: Photogeologic Investigations of  
(Name Only) Planetary Tectonic Features

PROPOSAL TITLE:

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) This proposal is for a 3-year renewal of NASA Grant NAGW-129, to support studies of the origin of tectonic landforms on the surfaces of the inner planets. This work entails mapping specific landforms, age-dating exposed surfaces, and developing models for the origin of surface features.

(b) During the past three years, several papers and abstracts on the origin and extent of compressional features surrounding Tharsis were published, as well as the results of dating and structural analyses of the Mars cratered terrain boundary. Work on the use of lunar basin location to infer prior polar positions was completed, as well as the geologic maps of 4 quadrangles of Ganymede (now in review).

(c) Continued funding will enable studies of the structural geology along the Mars cratered terrain boundary by analyzing the age sequence and distribution of specific landforms, and the comparison of mapped structures along the boundary with the tectonic sequence based on models for the formation and evolution of the boundary. Subsequent years of funding will concentrate on modeling the effects of subsurface topography and structure on formation of ridges and scarps on planetary surfaces.

(d) Maxwell, T.A. and McGill, G., Ages of Fracturing and Resurfacing in the Amenthes Region, Mars. Proc. Lunar and Planet. Sci. Conf., 18th, Cambridge Univ. Press, Lunar and Planetary Inst., p. 701-711 (1988).

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:**  
(Name, Address,  
Telephone Number)

Thomas B. McCord  
Planetary Geosciences Division, HIG  
University of Hawaii  
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Honolulu, Hawaii 96822 Phone: 948-6488  
~~NONE~~

**Co-INVESTIGATORS:**  
(Name Only)

**PROPOSAL TITLE:**

Remote Compositional Analysis of Lunar and Planetary  
Surfaces

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Continue for three years our investigation of the mineralogies of solar system objects with objectives: 1) add to knowledge of our planetary system; 2) develop techniques for remote sensing analysis; 3) train scientists. This program is essential to support the existing and planned planetary missions such as Galileo, MOM, Mars '94 OMEGA/VIMS, and CRAF/Cassini and it is not duplicated by any other investigator.

b. Results of the past year focus on the analysis of a large and varied spectrum and image telescopic data set we obtained for Mars during summer/fall of 1989, and include: 1) confirmation of the 3.8  $\mu\text{m}$  band, with analysis indicating: (i) a lower limit on the presence of carbonates of 1-3 wt%, (ii) potential presence of Sulfur compounds and/or Mars atmospheric CO; 2) better definition of a band in the 2.3  $\mu\text{m}$  region and analysis indicating hydrated minerals (clays) and /or atmospheric CO; 3) Spectral image cubes between 0.3 and 1.0  $\mu\text{m}$  showing well defined bands near 0.65 and 0.53  $\mu\text{m}$  and analysis indicating crystalline iron oxide for the first time; 4) a mixing model study of the spectral behavior of sulfates, carbonates, nitrates, and hydrates in palagonite as well as a study of the spectral behavior of palagonites.

c. The main emphasis this next grant year will be to continue the analysis of the large and varied telescopic data set we have acquired for Mars. This includes spectra and images in the 0.4 to 5.2  $\mu\text{m}$  spectral region. We will focus on three main topics: 1) search for salts and interpretations of several new absorption bands we have discovered in the 3.5-4.5  $\mu\text{m}$  region; 2) analysis of hydrate bands in the 2.0-3.0  $\mu\text{m}$  region; and 3) analysis of the crystalline iron oxide bands we discovered in the 0.4-1.0  $\mu\text{m}$  region. this will involve laboratory study of material optical properties. Planning will be done to direct the 1990 opposition observing program we plan to run. Mars is the emphasis for the current few years because of the unusually good oppositions for observation, our unique association of observing and analysis tools and expertise, and the need to support the various Mars missions.

d. Blaney, D.L. and T.B. McCord, Mars: A search for carbonates using reflectance spectroscopy. J. Geophys. Res., in press (1989). Blaney, D.L. and T.B. McCord, Carbonates sulfates and hydrates on the martian surface from infrared telescopic observations, in prep., JGR special Mars Conference Issue. Bell III, James F. and T.B. McCord, Mars: Near-infrared comparative spectroscopy during the 1986 opposition. Icarus, 77, 21-34 (1989). Bell III, James F., T.B. McCord, and P.G. Lucey, Detection of Crystalline Iron Oxide/Hydroxide Minerals on Mars. Science, submitted (1989). Bell III, James F., T.B. McCord, and P.G. Lucey, High spectral resolution visible to near-IR imaging and spectroscopy of Mars during the 1988 Opposition. Proceedings of the 4th Mars Symposium, Tucson, January 1989. J.G.R., in preparation (1989). Bell III, James F., T.B. McCord, and P.D. Owensby, Moderate spectral resolution visible to near-IR spectroscopy of Mars during the 1988 Opposition. Proceedings of the 20th Lunar and Planet. Sci. Conf., in preparation, March (1989).



## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Alfred S. McEwen  
(Name, Address, 2255 N. Gemini Dr., Flagstaff, AZ 86001  
Telephone Number) 602-527-7194; FTS 765-7194

Co-INVESTIGATORS: Laurence A. Soderblom  
(Name Only)

PROPOSAL TITLE: Thermophysics of Io

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objectives: Proposed here are four studies of Io that are extensions of previous work: (1) refined analyses of the IRIS data (for hotspot and passive temperature models) through improved pointing geometry of the Voyager 1 scan platform and correlation of IRIS with imaging data, (2) analysis of H<sub>2</sub>S on the surface and in the atmosphere, (3) improved surface compositional models based on comparison of Voyager multispectral mosaics with recently acquired laboratory spectral reflectivities of candidate materials, and (4) geophysical and geological interpretations of new geodetic and topographic models of Io.

b. Progress: new proposal

c. Work Plan FY90: (1) Complete solutions for camera pointing angles with Voyager images and use to predict pointing angles for IRIS observations. (2) Produce synthesized spectra from Voyager images and IRIS interferometer and radiometer; analyze for compositional implications. (3) Use the IRIS radiometer and interferometer observations for new background and hotspot thermophysical models. (4) Complete and publish paper describing evidence for H<sub>2</sub>S and significance.

d. Bibliography: (1) McEwen, A., 1988, Global color and albedo variations on Io: Icarus 73, 385-426. (2) McEwen, A., Johnson, T., Matson, D., and Soderblom, L., 1988, The global distribution, abundance, and stability of SO<sub>2</sub> on Io: Icarus 75, 450-478. (3) Gaskell, R., Synnott, S., McEwen, A., and Schaber, G., 1988, Large-scale topography of Io: Implications for internal structure and heat transfer: Geophys. Res. Lett. 15, 581-584. (4) McEwen, A., Lunine, J., and Carr. M., in press, Dynamic geophysics of Io, NASA SP-494, chapter 2.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Lucy-Ann McFadden  
(Name, Address, California Space Institute A-016  
Telephone Number) University of California, San Diego, La Jolla, CA 92093

**Co-INVESTIGATORS:** Mark V. Sykes  
(Name Only)

### **PROPOSAL TITLE:**

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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- a) This is a two part proposal. In Part I, we will examine the effect of the solar wind on the optical properties of meteorites to determine whether the solar wind can alter the properties of ordinary chondrite parent bodies, resulting in the spectral properties of S-type asteroids. Similarly, we will test carbonaceous chondrites to see if simulated solar wind bombardment produces the spectral features of C- and F-type meteorites. In part II, we will analyze the existing database of optical properties of asteroids to determine the effect of solar wind in altering asteroid surface properties. Justifications are: Previous studies of solar wind bombardment on lunar materials exist and can be built on and expanded. Problems of laboratory simulation of the solar wind are better known and can be overcome. New analytical techniques are available for determining the physical and chemical changes due to solar wind, enabling us to understand the processes producing observed optical changes. The structure of the solar wind in the asteroid belt is different than that used in simulations at the Moon. The asteroid database has not been systematically examined since the 1970's.
- b) New Proposal.
- c) Measure the optical properties of three ordinary chondrite meteorites (an H, L, LL), bombard them with 1-3 keV protons simulating the solar wind at doses that represent both ambient solar wind over time and high velocity, high density streams. Measure the neutral and ion mass spectrum above the sample. Use a Scanning Electron Microprobe at the surface of the sample before and after bombardment to document the physical-chemical changes independently of the optical properties. Measure the optical properties of the bombarded samples. Compare the results with existing asteroid optical properties, particularly the S-type asteroids located where the ordinary chondrite parent bodies should be, to evaluate the validity of the current working assumption used to interpret optical properties of asteroids: that asteroids are represented by unaltered, powdered meteoritic material.
- d) McFadden, Tholen and Veeder, 1989, The Physical Properties of Aten, Apollo, Amor Asteroids, Asteroids II, U. of Arizona Press. McFadden L.A. and Vilas, F., (1987). The 3:1 Kirkwood Gap as Sources of Ordinary Chondrites: Perspectives from Spectral Reflectance, Lunar and Planetary XVIII, 614-615, 1987.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: George E. McGill  
(Name, Address, Department of Geology and Geography  
Telephone Number) University of Massachusetts  
Amherst, MA 01003  
(413) 545-0140

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE: Planetary tectonics, areal geology, and geological history

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A. Objectives: To understand the tectonic behavior and evolution of planetary crusts. Geological mapping and topical studies of stratigraphy and geomorphology are combined with kinematic analyses of structures to infer crustal history. When possible, results are compared with the predictions of published geophysical models.

B. Accomplishments: Mapping of Ganymede Jg2 and Jg5 completed; discovered new 3300 km basin on Mars; constrained impact model for origin of martian crustal dichotomy, and revived endogenic hypothesis for the dichotomy; continued study of fracture history along martian dichotomy boundary.

C. Anticipated Effort: Revise Jg2 and Jg5; continue studies of martian northern lowlands and crustal dichotomy boundary; continue development of PC-based image-processing system.

D. Summary Bibliography: 1 paper, 4 abstracts, 5 presentations

McGill, G.E., Buried topography of Utopia, Mars: persistence of a giant impact depression, J. Geophys. Res., 94, expected in March, 1989.

McGill, G.E., Geologic evidence supporting an endogenic origin for the martian crustal dichotomy, Lunar Planet. Sci. XX, 667-668, 1989.

Dimitriou, A.M., Geologic evolution of the highland/lowland transition zone in the Ismenius Lacus quadrangle, Mars, Lunar Planet. Sci. XX, 246-247, 1989.

PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Names, Address,  
Telephone Number)

Chris McKay  
M.S. 245-3, NASA Ames Research Center  
Moffett Field, CA 94035  
(415) 694-5532

CO-INVESTIGATORS:  
(Name Only)

TITLE:

Evolution of Planets and Satellites

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objective: Use geophysical and astronomical data to develop and constrain self-consistent mathematical models of planetary processes and structures. Employ evolutionary calculations to increase understanding of contemporary features and phenomena as well as solar system formation and evolution. (b) Accomplishments: 1) Completed a parametric study of the thermal profile within an accreting icy satellite model of Rhea and calculated accretional temperature profiles for the nine major satellites of Saturn (Mimas-Rhea) and for all of the major satellites of Uranus. 2) Voyager data and model calculations indicate the possibility of higher bulk Ice/Rock ratios for Uranus and Neptune than previously expected. A scenario for differential accretion of planetesimals in a protoplanetary atmosphere has been described which could provide such high I/R ratios. 3) It has been argued that the thermal history of CAI's in Allende includes a heating event requiring high velocity entry into a transient atmosphere. SEM microprobe analyses have been used to help develop a formation profile for the growth of the meteorite parent body from which Allende material was derived. 4) Completed and published theoretical studies of icy bodies including cometary nuclei and Europa, and of the influence of phase changes upon solid state convection. (c) Proposed Work: 1) Complete theoretical study of the influence of accretional profiles on the thermal history and structure of the satellites of Saturn and Uranus. Include effects of melting in models. 2) Model the tectonic behavior of icy satellites, particularly Europa and Miranda, with a view toward explaining certain observed surface features. 3) Calculate the interaction of planetesimals with the envelopes of growing giant planets that form by the core-instability mechanism and its influence on their composition 4) Continue studies of CAI formation. (d) Bercovici, D., Schubert, G., and Reynolds, R.T., Geophys. Res. Letters, 13, 39-44, 1986; Podolak, M. and Reynolds, R.T., Icarus, 70, 31-36, 1987.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:

William B. McKinnon  
Dept. Earth and Planetary Sci.  
Washington University  
Saint Louis, MO 63130  
314-889-5604

CO-INVESTIGATORS:

None

TITLE:           Structure and Evolution of Outer Planet Satellites, NAGW-432

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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*a) Objectives and Justification:* the purpose of this work is to explore the structure, evolution, and bombardment of outer planet satellites. This includes understanding the origin and evolution of projectile populations (relevant to accretion timescales and the interplanetary correlation of geologic time), cratering mechanics in icy targets (morphology, phase changes, spallation, etc.), and the relative importance of large impacts, orbital dynamics, and internal processes for tectonics, with implications for interior properties.

*b) Accomplishments:* modeled Neptune's possible gas drag capture of Triton, finding it to be more plausible than previously thought; modeled the coupled tidal heating and orbital evolution of an initially eccentric Triton (as in a capture scenario), showing that a largely molten Triton evolves relatively slowly and may stay hot beyond the end of heavy bombardment; offered a prediction for Triton's density (to be determined by Voyager 2), assuming a capture origin and based on an analogy with Pluto/Charon; examined angular momentum budget for Pluto/Charon, finding that a large collision is required and that an upper limit to Charon's density can be set; used viscous relaxation of craters on Ariel to argue that a portion of Ariel's surface is  $\text{NH}_3\text{-H}_2\text{O}$  ice; synthesized other aspects of crater formation on the Uranian satellites; analytically modeled the formation of Ithaca Chasma.

*c) To be done this year:* further explore consequences of capture and alternative origins for Triton; further constrain relationships between projectile populations in solar system using new scaling derived from crater morphological studies; complete analysis of lineament patterns on Saturnian and Uranian satellites, and viscous relaxation on Ariel; analytically model formation Galileo-Marius Regio furrow system; constrain Ganymede, Callisto, and Tethys (and other intermediate-sized icy satellite) heat flow; complete study of Mercurian crater terrace widths, Mercurian and lunar ejecta blankets, and simple-to-complex crater model; revise Ganymede map.

*d) Publications:* McKinnon, W.B., and S. Mueller, 1988. Pluto's structure and composition suggest origin in the solar, not a planetary, nebula. *Nature* 335, 240-243; Mueller, S. and W.B. McKinnon, 1988. Three-layered models of Ganymede and Callisto: Compositions, structures and aspects of evolution. *Icarus* 76, 437-464; Schenk, P.M., 1988. Crater formation and modification on the icy satellites of Uranus and Saturn: Depth/diameter and central peak occurrence. *J. Geophys. Res.* 94, 3813-3832; Schenk, P.M. and W.B. McKinnon. Fault offsets and lateral crustal movement on Europa: Evidence for a mobile ice shell. *Icarus* 79, in press; McKinnon, W.B., and S. Mueller, 1989. The density of Triton: A prediction. *Geophys. Res. Lett.* 16, in press.

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## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** H. J. Melosh  
**(Name, Address,** Lunar and Planetary Lab, Univ. of Arizona  
**Telephone Number)** Tucson, AZ 85721 (602) 621-2806

**Co-INVESTIGATORS:** Ann M. Vickery  
**(Name Only)**

**PROPOSAL TITLE:** Impact Mechanics and the Evolution of the Terrestrial Planets

**ABSTRACT:** (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) This proposal consists of a number of related tasks that have in common the theoretical study of planetary evolution and surface processes. Using continuum mechanical models we can study the origin of the moon, impact evolution of atmospheres, fragmentation of objects in the asteroid belt, and various tectonic processes. Most of this work is heavily computer based and uses a number of hydrocodes, fragmentation algorithms, and a finite element code.

(b) In the past year we successfully completed four 3-D computations of an impact simulating the moon's origin. The implications of this impact for the thermal state of the early earth were also addressed. An analytic model for atmospheric erosion was constructed that indicates that a substantial fraction of Mars' primitive atmosphere could have been ejected by impacts during late heavy bombardment, in agreement with the geologic evidence for an early wet era. Work on a fragmentation algorithm for simulating the breakup of asteroids by impact has continued, and a hydrocode embodying the current algorithm constructed. A finite element model of the viscous relaxation of craters on Ganymede was constructed and showed that, contrary to analyses based on purely viscous models, the measured rheology of cold ice is in good agreement with the observations of craters. Tectonic models of the effects of loads on one-plate planets showed that there are two basic tectonic responses to loads, a small-planet (shell) response and a large-planet (plate) response. The implications of these models for the Tharsis rise on Mars were deduced. Graben mechanics was elucidated with an energy-based failure criterion.

(c) Next year's work will be principally concerned with analysis of the 3-D numerical models we have (and will) run at Sandia. Other tasks include numerical study of the impact evolution of planetary atmospheres, modeling the fragmentation of asteroids by a state-of-the-art fragmentation model, finite element models of the coronae on Venus, and a computer study of the morphology of craters formed in a Bingham medium.

(d) A.M. Vickery and H.J. Melosh, *Science*, 237, 738-743 (1987); H.J. Melosh, *Int. J. Impact Eng.* 5, 483-492 (1987); H. J. Melosh and M. E. Kipp, *LPSC XX* 685-686 (1989); D. M. Janes and H. J. Melosh, *J. Geophys. Res.* 93, 3127-3143 (1988); H. J. Melosh and A. M. Vickery, *Nature*, in press (1989).

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Albert E. Metzger  
(Name, Address, Jet Propulsion Laboratory M/S 183-501  
Telephone Number) 4800 Oak Grove Drive, Pasadena, CA 91109  
(818) 354-4017 (FTS) 792-4017  
Co-INVESTIGATORS: Eldon L. Haines  
(Name Only) \_\_\_\_\_

PROPOSAL TITLE: Planetary Gamma-Ray Spectroscopy Science Studies

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- 
- A. Gamma-ray spectroscopy is capable of measuring the surface composition of planets, asteroids, quiet comets, and many satellites, yielding results relevant to the origin, history and present state of the body. Gamma-ray spectrometer (GRS) experiments are currently under development for Mars Observer, planned for CRAF, and under consideration for subsequent Observer missions. Science studies are required to optimize instrument design and fully interpret flight data.
- B. Efforts to date have consisted of 1) developing the techniques with which a GRS can monitor atmospheric thickness and surface pressure at Mars by three different methods, 2) addressing issues of carbon in the regolith, stratigraphy, and atmospheric fractionation via the GRS at Mars, 3) analyzing the ability of the GRS neutron and gamma-ray modes to detect the possible presence of frozen  $H_2O$  at the lunar poles, and the ability to uniquely identify lunar rock types, 5) the first quantitative analysis of neutron-gamma-ray mode coupling, and 6) an analysis of laboratory data on the response of passive and active neutron modes.
- C. In the coming year we plan to 1) model the potential GRS capability for measuring polar cap composition and seasonal cycling at Mars, 2) analyze the ability of the GRS to derive stratigraphic information, 3) continue the analysis of thick target irradiation data, and possibly 4) resume development of the deconvolution technique for increasing GRS spatial resolution from orbit.
- D. Recent publications: 1) "The Application of Gamma-ray Spectroscopy to the Climatology of Mars", Lunar and Planetary Science (LPS) XVII, p. 549 (1986), 2) "Coupled Neutron/Gamma-ray Spectroscopy from Lunar Orbit", LPS XVIII, p. 824 (1987), 3) "Gamma-ray Differential Attenuation: A Means of Measuring Atmospheric Thickness at Mars", 4th Internl. Conf. on Mars, (1989), 4) "Gamma-ray Methods for the Measurement of Atmospheric Thickness and Surface Pressure at Mars", LPS XX, p. 687 (1989), 5) "The Identification of Lunar Rock Types and Search for Polar Ice by Gamma-ray Spectroscopy from a Small Spacecraft", accepted by JGR.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Henry J. Moore  
(Name, Address, 345 Middlefield Rd., Menlo Park, CA 94025  
Telephone Number) (415) 329-5175 FTS 459-5175

CO-INVESTIGATORS: \_\_\_\_\_  
(Name Only) \_\_\_\_\_

PROPOSAL TITLE: Viking Landers Beyond Sol 921

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objectives and Justification. This is a request for a renewal of a 2-yr proposal funded in FY89. The objectives are to (1) acquire additional data on the distribution of surface materials at the Viking landing sites, (2) refine estimates of expected remote sensing signatures and compare them with the actual ones, and (3) finish writing a U.S. Geological Survey Professional Paper. A more accurate assessment of the areal distributions of the various surface materials will improve our understanding of the radar and thermal remote-sensing signatures at the sites. Documentation of the final phases of both landers is required for completeness.

b. Progress. Two papers have been accepted for publication. Mapping of the far fields at the landing sites will start in June 1989; a proposal for the assignment of a Planetary Geology - Geophysics Undergraduate Research Intern to assist in the mapping has been submitted. A model relating the mechanical properties of soillike materials with their remote-sensing signatures is being developed.

c. Work Plan FY 90. Efforts will be directed toward analyzing maps of the far fields of the landers, reestimating the remote-sensing properties of the sites, and completing the writing of the professional paper.

d. Summary Bibliography.

Moore, H.J. and Jakosky, B.M., 1988, Rpts. PGGP., NASA TM 4041, p. 188-190.

Moore, H.J. and Jakosky, B.M., 1988, LPSC XIX, p. 800-801.

Dale-Bannister, M.A. et al., 1988, LPSC XIX, p. 239-240.

Arvidson, R.E., Gooding, J.L., and Moore, H.J., 1989, Rev. Geophys. Space Phys., in press.

Moore, H.J. and Jakosky, B.M., 1989, Icarus, in press.



## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Henry J. Moore  
(Name, Address, U.S. Geological Survey, 345 Middlefield Road  
Telephone Number) Menlo Park, CA 94025

CO-INVESTIGATORS: Gary D. Clow  
(Name Only)

PROPOSAL TITLE: Goldstone 1986-88 Radar of Mars

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one of two of your recent publications relevant to the proposed work.)

a. Objectives: To examine the 1986 - 1988 Goldstone radar observations of Mars at 3.8- and 12.6-cm wavelengths. There are six objectives: (1) correlate the radar data with the geology shown on high-resolution Viking orbiter images, (2) interpret the diffuse echoes in terms of geologic conditions, (3) provide information on potential future landing sites, (4) compare reflectivities and surface roughnesses at two wavelengths, (5) confirm results from previous radar experiments, and (6) obtain probability density distributions of quasi-specular and diffuse echo reflectivities and quasi-specular echo surface roughness estimates. The results will be published on a timely basis.

b. Progress: We have developed a model for 12.5-cm depolarized echoes from Mars that accounts for the total cross-sections as a function of longitude along 7°S and 22°N and broadly matches observed echo spectra.

T. W. Thompson has normalized and reduced the 1986 Goldstone polarized echoes. Preliminary analyses of quasi-specular echoes indicate that reflectivities (and dielectric constants) are bimodal. Similar results are obtained for thermal inertias at the subradar points. Both reflectivities and thermal inertias along 7°S produce curves with similar forms showing that there is a direct correlation between them.

Preliminary work on modeling the polarized echoes is under way.  
c. Work Plan FY90: Principal efforts will be directed toward refining the analyses of the polarized echoes. The analyses will improve the estimates of normal reflectivities and root-mean-square slopes from the quasi-specular echoes. Modeling will continue. We plan to continue correlating our results with the geologic, thermal inertia, albedo, and color data on Mars. Results will be reported on a timely basis.

d. Summary Bibliography:

Thompson, T. W. and Moore, H. J., 1989, A model for depolarized echoes from Mars: Proc. 19th Lunar & Planet. Sci. Conf., p. 409 - 422.  
See Bibliography for abstracts.

**PROPOSAL SUMMARY**  
(not more than 2 pages, including bibliography)

**TITLE:** "Geomorphic Analysis of High Resolution Images of Mars and the Moon"

**PRINCIPAL INVESTIGATOR:** Dr. Peter J. Mouginiis-Mark

**INSTITUTION:** Planetary Geosciences Division  
Hawaii Institute of Geophysics  
University of Hawaii

**CO-INVESTIGATOR(S):** None  
(Names only)

**ABSTRACT**

List (a) overall objectives and justification of the work; (b) progress and accomplishments of the prior year, or "new proposal"; (c) listing of what will be done this year, as well as how and why; (d) bibliography.

**A) Objectives:** To further investigate the small-scale (sub-kilometer) geomorphology of the surface of Mars, the Moon and Venus in order to constrain the geologic processes responsible for the emplacement of fluidized ejecta around impact craters on Mars, the possible geomorphic influence of martian ground-ice, and the degradation of lunar and venusian impact craters. Digital and high-resolution Viking Orbiter images will be used in the analysis of the martian landforms, and new high-resolution radar data of Zisk (3.0 cm wavelength; 15-30 m resolution), Thompson (70 cm; 800-1,000 m), and Campbell (~1 km for Venus) will be used to study lunar and venusian crater deposits.

**B) Work Plan:** Task #1: Using digital Viking Orbiter images, the PICS software package, and photoclinometric programs developed by USGS Flagstaff, we will measure the topography and volume of ejecta deposits and impact craters on Mars. The topography of approximately 50 craters will be studied in detail over the 3-year effort. These data will be used to develop geologic models for ejecta emplacement and the modification of the crater cavity. Very high resolution (<20 m/pixel) Viking images of fresh impact craters will also be used to search for diagnostic landforms indicative of material flow, erosion, and other geomorphic processes. Task #2: Radar phase information for the Moon and Venus will be used to determine the areal extent and physical properties of young large lunar and (presumed) Venus craters.

**C) Progress:** First Year funding for this project has not yet been received, so that only work by graduate students has been carried out under the auspice of student projects. Radar scattering properties of the lunar crater Bessel, and of Meteor Crater, have been studied, and techniques for the derivation of digital elevation data from Viking Orbiter images have been investigated. 3 abstracts on these subjects have been co-authored by the students and presented at LPS XX.

**D) Bibliography:** 1) Mouginiis-Mark, P.J. (1979). Martian fluidized crater morphology: Variations with crater size, latitude, altitude, and target material. J. Geophys. Res. 84, 8011-8022. 2) Mouginiis-Mark, P.J. (1981). Ejecta emplacement and modes of formation of martian fluidized ejecta craters. Icarus 45, 60-76. 3) Mouginiis-Mark, P.J. (1987). Water or ice in the martian regolith? Clues from rampart craters seen at very high resolution. Icarus, 71, 268-286. 4) Campbell, B.A., Zisk, S.H., and Mouginiis-Mark, P.J. Lunar scattering from new 3-cm polarization and phase radar data. Lunar Plan. Sci. XIX, 160-161.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:**  
(Name, Address,  
Telephone Number)

Dr. Ahobila Vajjula Murali

Lunar & Planetary Inst., 3303 NASA Rd. One,  
Houston, TX 77058, (713) 486-2193/ (713) 483-5204

**Co-INVESTIGATORS:**  
(Name Only)

**PROPOSAL TITLE:** RAMGARH CRATER, INDIA: INTEGRATED FIELD, PETROCHEMICAL,  
AND GEOCHRONOLOGICAL INVESTIGATIONS

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

*Morphology and the available literature of Ramgarh Crater, India (25° 20' N; 76° 37' 30" E; located ~50 km north of Deccan volcanic province) strongly suggest that it is an impact structure.*

*a) We propose a multidisciplinary investigation of Ramgarh Crater to confirm its impact origin, age of emplacement, nature and composition of projectile and the target lithologies. Proposed work involves both field studies and the laboratory investigations including petrography, microprobe, AEM, STEM, INAA and  $^{40}\text{Ar}/^{39}\text{Ar}$  age determination (incremental heating) techniques. This study would strengthen our understanding of the impact history of the Earth and help us to evaluate any possible temporal relationship of this cratering event to the Deccan volcanic episode.*

*b). New Proposal- As this is a new proposal no work relates directly to it but our published work on Lonar (India), Wabar (Saudi Arabia), Kara and Ust-Kara (USSR) Craters and the Libyan Desert Glass (Egypt) may be considered.*

*c). We plan field work and sample collection at Ramgarh Crater, India before December 1989. Two scientists from the U.S. (A. V. Murali and V. L. Sharpton, LPI) would participate in the field work along with the collaborator from India (V. K. Nayak). After the preliminary petrographic studies, samples would be identified for the proposed laboratory studies that follow.*

*d). (1) Murali, A. V., Zolensky, M. E. and Blanchard D. P (1987) Tektite-like bodies at Lonar Crater, India: Implications for the origin of Tektites. J. Geophys. Res., 92, E729-E735. (2) Horz, F., See, T. H., Murali, A. V., and Blanchard, D. P. (1989) Heterogeneous dissemination of projectile materials in the impact melts from Wabar Crater, Saudi Arabia. Proc. Lunar Planet Sci. Conf. 19th, 697-709. (3) Koeberl, C., Harrison, T., Sharpton, V. L., Murali, A. V., and Burke, K (1989) The Kara and Ust-Kara impact structure (USSR) and their relevance to the K/T boundary event. Geology (Submitted).*

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Bruce Murray  
**(Name, Address,** Caltech, 170-25, 1201 E. California Blvd.,  
**Telephone Number)** Pasadena, CA 91125 818/356-3780

**Co-INVESTIGATORS:** Arden Albee  
**(Name Only)** \_\_\_\_\_

**PROPOSAL TITLE:** Surficial Volatiles on Mars

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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### **ABSTRACT**

(a) Viking left unresolved the weathering and sedimentation processes responsible for the chemistry and morphology of Mars' present surface deposits. In particular, many attributes of the martian surface testify to prolonged mechanical and chemical weathering in Mars' strongly oxidizing, low temperature/pressure environment. Water must somehow be involved in these processes. The goal of our research is to better delineate water's role in the development of martian surface deposits at present and in the past. Our aim is to develop hypotheses about near-surface water in any state, how its chemical and mechanical activity influenced past behavior and large scale mass movements, and the nature of martian soil. We propose specific tests of our hypotheses by new orbital and surface observations expected in the 1990's.

(b) Renewal for 3rd year of 3 year study.

(c) Two efforts are planned to be concluded this year:

1. Definitive comparison of terrestrial and martian landslide morphology and distribution using Landsat and Viking Orbiter images, with supporting analyses of landslide mechanisms.

2. Quantitative analysis of the atmospheric/soil exchange of water vapor including the effects of cold trapping due to local surface roughness.

(d) Shaller and Murray, 1988; Shaller and Murray, 1989; Svitek and Murray, 1988a; Svitek and Murray, 1988b; Svitek and Murray, 1989a; Herkenhoff and Murray, 1988; Albee 1987.

## ABSTRACT

PRINCIPAL INVESTIGATOR: Douglas B. Nash  
San Juan Capistrano Research Institute  
31878 Camino Capistrano, Suite 278  
San Juan Capistrano, California 92675  
(714) 240-2010

CO-INVESTIGATORS: None

PROPOSAL TITLE: SURFACE PROPERTIES OF PLANETARY BODIES

OBJECTIVES: Study spectral reflectance, surface composition, charged-particle and UV irradiation effects, and electrodynamic surface properties of the Galilean and other planetary satellites and especially Io. Conduct key experiments and use lab and thermodynamic data to interpret spacecraft and groundbased observational data, and derive improved composition and surface process models for these satellites and other planetary bodies.

PROGRESS: Experimental calorimetric study of vacuum-weathered sulfur (with J. Gooding); found that the polymeric form of sulfur may be continually enriched in Io sulfur deposits by repeated volcanic recycling (melting) and vacuum weathering. Lab study (with J. Moses) of time-dependent spectral properties of frozen sulfur; deduced physics of spectral aging process associated with solid-state phase changes, and rapid aging and systematic changes in color and spectra of sulfur; predicts large transient optical effects on Io when liquid sulfur freezes there. Interpreted new IR spectra of Io (with R. Howell) using lab spectra of H<sub>2</sub>S and SO<sub>2</sub> ice, frost, and gas; identified absorption features in Io spectrum which we attribute to H<sub>2</sub>S and SO<sub>2</sub>; showed for first time that H<sub>2</sub>S is a widespread but largely transient component on Io's surface, and that it could explain post-eclipse brightening. Began formulation of detailed quantitative theoretical model on the fundamentals of vacuum weathering (with S. Baloga)

PROPOSED WORK (for FY 90): (1) Continue laboratory work on vacuum weathering of sulfur and experimental and theoretical modeling of process on Io. (2) Continue study of thermodynamic properties of vacuum-mature polymeric and related sulfur phases (with J. Gooding). (3) Continue work on lab spectra of H<sub>2</sub>S/SO<sub>2</sub> mixtures, and experimental modeling of H<sub>2</sub>S physics on Io's surface. (4) Continue work (with S. Baloga) on theoretical model for sublimation (vacuum) weathering of planetary surfaces.

BIBLIOGRAPHY: Nash and Howell (1989), H<sub>2</sub>S on Io: evidence from telescopic and laboratory infrared spectra, SCIENCE (in press). Nash & Moses (1988), Vacuum weathering of sulfur: temperature effects and applications to Io, GEOPHYS. RES. LETT., 15, 697-700. Howell, Nash, Geballe, & Cruikshank (1989), High resolution infrared spectroscopy of Io and possible surface materials, ICARUS, 78, 27-37. Nash and Gooding (1989), Vacuum-weathered sulfur: calorimetric evidence for unusual phase composition, LUN. PLAN. SCI., 20, 760-761.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** William J. Nellis, Lawrence Livermore National Laboratory  
(Name, Address, P. O. Box 808, Livermore, CA 94550  
Telephone Number) (415) 422-7200

**Co-INVESTIGATORS:**  
(Name Only)

**PROPOSAL TITLE:** Properties of Planetary Fluids at High Pressures and Temperatures

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objectives: The goals are measurements of equation-of-state (EOS), electrical-conductivity and shock-temperature data of fluids thought to exist in the interiors of the giant planets. Conductivity data is needed for dynamic or kinematic calculations of the magnetic fields of Uranus, Neptune, Jupiter, and Saturn. Shock-wave EOS and shock-temperature data are needed to validate theoretical EOS and for analyzing electrical conductivity data. Fluids of particular interest are  $H_2$ ,  $H_2-H_2O$ , and "synthetic Uranus."

(b) Progress: New Proposal

(c) Work Statement: We will complete measurements of electrical conductivities and shock temperatures of liquid  $H_2$  and double-shock EOS points for synthetic Uranus; develop a conductivity specimen holder for quasi-isentropic compression of synthetic Uranus to 150 GPa (1.5 Mbar); develop a high-pressure low-temperature specimen holder for shocking liquid  $H_2$  from the critical point to achieve higher temperature shock states.

(d) W. J. Nellis, D. C. Hamilton, N. C. Holmes, H. B. Radousky, F. H. Ree, A. C. Mitchell, and M. Nicol, "The Nature of the Interior of Uranus Based on Studies of Planetary Ices at High Dynamic Pressure," Science 240, 779-781 (1988).

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Philip D. Nicholson  
(Name, Address, Telephone Number) 418 Space Sci. Bldg., Cornell Univ.,  
Ithaca, NY 14853-6801 (607)255-8543

**Co-INVESTIGATORS:**  
(Name Only)

**PROPOSAL TITLE:** Dynamical Studies of Planetary Rings

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objectives: To characterize the dynamical processes which control the structure and evolution of planetary ring systems, and the physical properties of the particles which comprise them.

(b) Progress: (1) Analyzed several sets of Voyager images of the Keeler Gap in Saturn's outer A Ring. We have found significant (10 km peak-peak) variations in all images, but with two distinct wavelengths: 7 degrees and 13 degrees. (2) Reduced data from stellar occultations by Neptune in 1987 and 1988, and found evidence for an additional ring arc at a radius of 34900 km. Wrote two reviews on the current state of observational evidence for the Neptunian arcs, and on the theoretical models proposed to describe them. (3) Obtained the first near-infrared images of the Jovian ring and its 'shepherd' satellites, Metis and Adrastea. Orbit solutions for both satellites are compatible with Voyager results from 1979, but with greatly improved orbital periods.

(c) New work: (1) Complete the photometric analysis of the C Ring, by fitting scattering models to the brightness scans obtained from Voyager images. (2) Analyze observations of the occultation by Saturn's ring of 28 Sgr to be made in July 1989, both to further refine kinematic models for variable-radius features and to characterize the cm-scale size distribution. (3) Develop software to merge ground-based occultation data for Neptune's ring arcs with imaging and occultation data to be obtained during the Voyager encounter. (4) Obtain near-infrared images of Neptune, and any close satellites above 200 km in diameter, and of Saturn's rings and 'ring-moons'.

(d) Bibliography: Nicholson and Porco (1988) JGR 93, 10209; 3 additional papers accepted for publication; (1 invited review talk and 2 contributed papers presented at AGU (May 1989) and DPS (Oct 1988) meetings. 3 invited colloquia.)

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Name, Address,  
Telephone Number)

Peter L. Olson

The Johns Hopkins University

Baltimore, Maryland 21218

(301) 338-7707

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE:

Mantle Plume Dynamics in the Terrestrial Planets

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) This proposal is a request for renewed support to investigate the mechanics of transolidus plumes in the mantles of the terrestrial planets. The objectives of this research are two-fold. First, we intend to develop a numerical model of two-phase thermal plumes, including flow of the subsolidus mantle plus the formation of melts and their percolation through the subsolidus matrix. This model will be sufficiently general to be applicable to problems of hotspot-type volcanism in terrestrial planets. Second, we intend to use the model to determine the relative importance of magmatic versus conductive surface heat transfer associated with mantle plumes on Venus and on the Earth. In particular, these calculations should help resolve the controversy regarding the importance of magmatic heat transfer in the energy budget in the interior of Venus.

(b) progress report

(c) The research consists of constructing, testing and applying a numerical model for thermal plumes which explicitly includes the mechanical effects of melt formation, solidification and percolation.

(d) Olson, P. and G. Schubert, Plume formation and lithosphere erosion: a comparison of laboratory and numerical experiments, J. Geophys. Res. 93, 15065-15084, 1988.



## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James B. Orenberg (415) 338-1292  
(Name, Address, San Francisco State University  
Telephone Number) Dept. of Chemistry & Biochemistry  
1600 Holloway Avenue, San Francisco, CA 94132

Co-INVESTIGATORS:  
(Name Only)

Ted L. Roush

Determination of the Optical Constants of Hydrates,  
Carbonates, Sulfates, and Nitrates for the Interpre-  
tation of Thermal Infrared Spectra of Martian Surface

PROPOSAL TITLE:

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. The relative abundances, chemical compositions, and mineralogies of volatile-bearing compounds (e.g. carbonates, sulfates, hydrates, and nitrates) provide important information regarding the evolutionary history of the martian surface and atmosphere. Until samples are returned from well characterized sites on Mars, remote sensing observations will provide the only means of obtaining information regarding the surface and atmospheric constituents of Mars. Several absorption features present in recent thermal infrared observations of Mars indicate the presence of hydrates present on the martian surface, and  $\text{CO}_3$ - and  $\text{SO}_4$ -bearing materials within the dust suspended in the martian atmosphere. The position of these features indicate that the  $\text{CO}_3$  and  $\text{SO}_4$  is located in distorted crystallographic sites. Quantitative modelling of these data currently rely upon optical constants of calcite and anhydrite, neither of which exemplify minerals with distorted sites. The goal of the proposed research is to derive the infrared (2.5-25 $\mu\text{m}$ ) optical constants for more pertinent volatile-bearing materials. These materials include: 1)hydrous and anhydrous carbonates; 2)hydrous and anhydrous sulfates; 3)hydrated and/or hydroxylated silicates; and 4)hydrous and anhydrous nitrates.

b. New Proposal

c. During the first year carbonates and sulfates, whose infrared transmission spectra are consistent with recent thermal infrared measurements of Mars, will be acquired, chemically and structurally characterized, their near-normal reflectivity measured, and their optical constants derived.

d. Roush, T.L., J.B. Pollack, C. Stoker, F. Witteborn, J. Bregman, D. Wooden, and D. Rank  $\text{CO}_3^{2-}$ - and  $\text{SO}_4^{2-}$ -Bearing anionic complexes detected in martian atmospheric particulates, presented at the 4<sup>th</sup> International Conference on Mars, Tucson, AZ, January 1989.  
Roush, T.L. J. B. Pollack, C. Stoker, F. Witteborn, J. Bregman, D. Wooden, and D. Rank  $\text{CO}_3^{2-}$ - and  $\text{SO}_4^{2-}$ -Bearing anionic complexes detected in martian atmospheric dust, Lunar and Planetary Science Conference XX, Lunar and Planetary Institute, Houston, TX, 928-929.

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## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:

Steven J. Ostro  
300-233  
Jet Propulsion Laboratory  
Pasadena, CA 91109  
818/354-3173

TITLE:        ASTEROID LIGHTCURVE INVERSION

### ABSTRACT

A. Objective: Application of a new approach, called convex-profile inversion (CPI), to analysis and physical interpretation of asteroid lightcurves. CPI identifies the optimal shape constraint derivable from a non-opposition lightcurve as the asteroid's "mean cross section"  $\bar{Q}$ , a convex profile equal to the average of the convex envelopes of all the surface contours parallel to the equator.  $\bar{Q}$  is a unique, rigorously defined, 2-D average of the 3-D shape. For an opposition lightcurve,  $\bar{Q}$ 's odd harmonics are not accessible, and CPI yields the symmetrized mean cross section,  $\bar{Q}_S$ .

B. Progress: A journal article (Ostro et al. 1988, *Icarus* 75, 30-63), presents CPI as a comprehensive theory about an asteroid lightcurve's information content, and reports many of the 1984-88 results of this research, including (i) calibration of systematic sources of error, employing simulations based on Hapke's photometric function; (ii) development of procedures for algebraic manipulation of profiles, so one can combine weighted estimates of  $\bar{Q}$  from independent lightcurves; (iii) development of mathematical tools for the quantitative description and comparison of convex profiles; (iv) numerical calculation of  $\bar{Q}$  and  $\bar{Q}_S$  for actual 3-D shapes, to convey visually the physical meaning of shape averages; and (v) estimation of  $\bar{Q}$  and/or  $\bar{Q}_S$  for selected asteroids.

C. Proposed Work: 1) Apply CPI to 24- and 120-color lightcurves obtained by M. Gaffey for the large S-class asteroid 15 Eunomia, using  $\bar{Q}(\lambda)$  to constrain the longitudinal distribution of surface units having different compositions or scattering properties. 2) Apply CPI to asteroids for which lightcurves are available at thermal-IR as well as at visible wavelengths, to constrain the rotation sense. 3) Explore novel approaches to imaging planetary bodies.

D. 1988 Publications: 1) Ostro, S. J., R. Connelly, and M. Dorogi (1988). Convex-Profile Inversion of Asteroid Lightcurves: Theory and Applications. *Icarus* 75, 30-63. 2) Ostro, S. J., R. Connelly, and L. Belkora (1988). Asteroid Shapes from Radar Echo Spectra: A New Theoretical Approach. *Icarus* 73, 15-24 (1988).

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: E. M. Parmentier  
(Name, Address, Department of Geological Sciences  
Telephone Number) Brown University (401) 863-3338

Co-INVESTIGATORS: None  
(Name Only)

PROPOSAL TITLE: Planetary Geophysics and Tectonics

### **Abstract**

Research funded by grant NSG-7605, representing work that we will complete during the current 18 month funding period 3/1/87-9/31/89, has focussed in the following three areas. (a) We have predicted a relationship between the wavelength, which could be expressed as either the width or spacing of tectonic features, and surface elevation (1). This is a consequence of the dependence of both the density and strength stratification, which control the isostatic elevation and dominant wavelengths, respectively, on temperature distribution and crustal thickness. There is a preliminary suggestion that the type of correlation that we predicted can be observed on Venus. (b) Convection in the interior of a planet is ultimately responsible for long wavelength topography and tectonics at its surface. In the terrestrial continents, with a thick granitic crust, and on Venus, where the surface temperature is high, the lower crust can flow in response to forces exerted on it from a convecting mantle beneath. We examine surface topography and deformation due to convection beneath a ductile crust and consider the implications for the origin of Venusian highlands. (c) We have also formulated a finite amplitude necking model for the evolution of a rift zone that forms by faulting (2). This model illustrates two important aspects of rift evolution that previous models do not explain: the narrowing of a rift and the finite strain that accumulates as extension proceeds. This explains important aspects of terrestrial rift zones and the Beta Regio rift on Venus.

We propose three new studies. (a) To understand the formation of rifts, it is necessary to consider how a rift develops along strike. This along strike development can be envisioned as the propagation of a crack into an elastic plate. We propose to continue our studies of rift propagation by treating the rift (crack) as a region of finite amplitude necking. We will also study the role of buoyancy forces in driving rift propagation. (b) We also propose to study the role of compositional buoyancy due to partial melting and melt extraction in the structure and evolution of mantle plumes. Dynamical behavior resulting from the combined effects of thermal and compositional buoyancy (3) could have important implications for the formation and evolution of swells on Venus, Mars, and the Earth. (c) Finally we propose to develop plume models to examine the formation and evolution of swells on Venus. This will allow us to correlate geophysical data, such as the height of swells and their apparent depth of compensation, with geologic data on volcanism and tectonism.

**References:** (1) Zuber and Parmentier, On the relationship between isostatic elevation and the wavelengths of tectonic surface features on Venus, submitted to *Icarus*, 1989. (2) Parmentier, Stofan, and Head, A finite amplitude model for the formation and evolution of rift zones: application to the Beta Regio Rift, *Lunar and Planetary Science* 18, 764-765, 1987. (3) Sotin and Parmentier, Dynamical consequences of thermal and compositional density stratification beneath spreading centers, submitted to *Geophys. Res. Lett.*, 1989.

## PROPOSAL SUMMARY SHEET—ABSTRACT

PRINCIPAL INVESTIGATOR: Chris W. Patterson

Los Alamos National Laboratory  
Theoretical Division, MS J569  
P.O. Box 1663  
Los Alamos, NM 87545  
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COLLABORATOR AND AFFILIATION: Dominique Spaute

Planetary Science Institute  
2030 East Speedway Suite 201  
Tucson, AZ 85719

### RESONANCE ACCRETION IN THE SOLAR NEBULA

(a) Objectives: To model the accretion of planetesimals at orbital resonances of embryo planets. We will include the effects of resonance splitting due to the induced precession of orbits by the solar nebula. We shall also model planetesimal collisions within the resonance zone. We will determine which resonances lead to collisional disruption and which lead to accretion of planetesimals. We hope to demonstrate that resonance splitting and planetesimal collisions within resonance zones can enhance resonance capture and impart prograde rotations to accreting embryos.

(b) Progress: See Appendices A & B.

(c) Proposed Work: It has been shown that orbital resonances can trap planetesimals and prevent their decay due to gas drag in the solar nebula. Such resonances also damp the motion of planetesimals so that they converge to the same orbit with the same phase. We now use an effective potential for the solar nebula which causes the resonances to split. We will also use additional damping terms to describe collisions within the resonance and compare with many-body trajectories using effective collisional cross sections. By including planetesimal collisions and solar nebula splitting we can more accurately determine accretion capture strengths and time scales. Preliminary work has already shown the resonance accretion will lead to prograde rotations. This work allows us to determine the efficiency of converting orbital to rotational angular momentum in the resonance accretion process.

(d) Bibliography: S.J. Weidenschilling and D.R. Davis (1985) Orbital resonances in the solar nebula: Implications for planetary accretion; C.W. Patterson (1987) Resonance capture and the evolution of the planets.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: S. J. PEALE  
(Name, Address, DEPARTMENT OF PHYSICS, UNIVERSITY OF CALIFORNIA  
Telephone Number) SANTA BARBARA, CA 93106 (805)961-2977

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE:

SOLAR SYSTEM PHYSICS

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. The overall objectives are to understand the dynamical evolution of solar system configurations leading to constraints on their histories, infer the origin of various resonant configurations, constrain properties of planetary interiors and develop techniques in dynamics which air in this understanding. Constraints on nebular models affecting rates of planetary accretion are also sought.

b. Progress: A paper "On the density of Halley's comet" has been completed and submitted to *Icarus*, revised in response to referee comments and resubmitted. Although reasonable densities near  $1 \text{ g/cm}^3$  are obtained for a variety of parameter values, the uncertainties are such that meaningful constraints on the density cannot be established by this or any other calculation. A paper "Some unsolved problems in evolutionary dynamics in the solar system" has been accepted for publication in *Celestial Mechanics*. A paper "Rotation of Halley's comet" has been accepted for publication in *Icarus*. Abstracts of these papers are attached.

c. Proposed work (Over a period of more than one year) I have agreed to write a short chapter on the rotational properties of natural satellites for an "Astrophysics Encyclopedia". Otherwise, the proposed work is the same as that detailed in my full proposal submitted last fall with the exception of the paper on the density of Halley's comet which has been completed. This includes the model for the arc rings of Neptune, possibility of a disruption of a primordial 2/1 Ariel/Umbriel orbital resonance, effects of gas drag on planetary accretion, inconsistencies between theory and observation for the Galilean satellite system, evolution of the Titan-Hyperion orbital resonance and effect of nebular dissipation on the amplitude of libration of the Trojan asteroids.

d. Recent publications: Peale, S. J. (1988) Speculative histories of the Uranian satellite system, *Icarus* **74**, 153-171. Peale, S. J., and Lissauer, J. J. (1989) The rotation of Halley's comet, *Icarus*, In press. Peale, S. J. (1989) Some unsolved problems in evolutionary dynamics in the solar system, *Celestial Mechanics*, In Press. Peale, S. J. (1989) On the density of Halley's comet, submitted to *Icarus*.

## PROPOSAL SUMMARY

### PRINCIPAL INVESTIGATOR:

Roger J. Phillips  
Southern Methodist University  
Department of Geological Sciences  
Dallas, TX 75275  
(214) 692-3196

CO-INVESTIGATORS: Robert E. Grimm, Southern Methodist University

PROPOSAL TITLE: Planetary Interior Modeling and Tectonic Implications

### ABSTRACT:

- a. *Objective:* Gain an improved understanding of the relationship between the thermal evolution and the tectonic evolution of terrestrial planetary bodies. Specific objectives include analysis and interpretation of Venusian gravity data and tectonic models for Venus with emphasis on convective stress coupling to the lithosphere, models for gravity detachment tectonics, the development of thrust faults, the large-scale deformation of lithospheres using a two-dimensional thin viscous sheet model, and the thermal history of asteroids and meteorites.
- b. *Progress:* 1) Completed first phase of work on the initiation of thrusting and carried out a preliminary analysis for terrestrial oceanic lithosphere. 2) Completed preliminary modeling and interpretation of Bell Regio and Tellus Regio gravity anomalies [Smrekar and Phillips, 1989]. 3) Carried out new analyses in response to reviews of convective stress coupling paper [Phillips, 1989a,b]. 4) Formulated finite element thin viscous sheet model for application to tectonic deformation of Lakshmi Planum on Venus.
- c. *Proposed work:* 1) Test hypothesis of convective stress coupling. 2) Complete study of gravity detachment model for Venus by carrying out 2-dimensional ( $x,z$ ) analyses. 3) Extend work on the initiation of subduction (thrust faults) by incorporating elastic/plastic rheology and extending analysis to Venus. 4) Test Bell-Tellus modeling results at other localities on Venus. 5) Test formation of Lakshmi Planum with 2-d ( $x,y$ ) thin viscous sheet model. 6) Analyze thermal evolution of asteroids and meteorites considering unipolar dynamo induction heating.
- d. *Summary bibliography:* (9/88 - 3/89) 3 papers published; 1 paper in press; 1 paper in revision; 2 abstracts published; 1 seminar given; 2 papers presented at meetings; e.g., Finnerty, A. A., R. J. Phillips, and W. B. Banerdt, Igneous processes and closed system evolution of the Tharsis region of Mars, *J. Geophys. Res.*, 93, 10,225-10,235, 1988. Phillips, R. J., Convection-driven tectonics on Venus. I Analysis, reviewed and in revision for *J. Geophys. Res.*, 1989. Smrekar, S. and R. J. Phillips, Implications of gravity modeling for a thermal isostasy hypothesis for Bell Regio, Venus, *LPSC XX*, Lunar and Planetary Institute, Houston, 1028-1029, 1989. Phillips, R. J., Tectonic response to mantle dynamics in Venus, *LPSC XX*, Lunar and Planetary Institute, Houston, 842-843, 1989.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Carle M. Pieters  
(Address, Phone) Department of Geological Sciences  
Brown University  
Providence, RI 02912  
(401/863-2417)

TITLE: REFLECTANCE EXPERIMENT LABORATORY (RELAB) NAGW-748

ABSTRACT: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year; c. brief listing of what will be done this year as well as how and why; and d. recent publications relevant to the proposed work.

a) The Reflectance Experiment Laboratory (RELAB) is operated as a multiuser NASA facility maintained at Brown University. The overall purpose of the design and operation of the RELAB spectrometer is to obtain precise, high spectral resolution, bidirectional reflectance spectra of materials in the visible and near-infrared. One of the key elements of the laboratory is the ability to obtain reflectance measurements using viewing geometries specified by the user. This allows investigators to simulate, under controlled laboratory conditions, reflectance spectra as they would be obtained remotely (i.e. with telescopic, spaceborne, or airborne instruments). Geometry dependent reflectance properties of materials can also be investigated. The high precision ( $<1/4\%$ ), broad spectral coverage (0.3 to  $\sim 3.6\mu\text{m}$ ), and flexible sample configuration of this unique spectrometer make the RELAB facility well suited for the laboratory science studies required for the remote analysis of surface composition and physical properties using advanced sensors in current programs and on future missions.

The RELAB is maintained under a cooperative agreement between Solar System Exploration Division and the Land Processes Branch of Earth Science and Applications. Under this arrangement a portion of RELAB time is made available to researchers in funded NASA programs on a no cost basis. Research topics of investigators using the RELAB are reviewed and funded by NASA separately. Since advanced spectroscopic sensors will be the cornerstone of future remote sensing science, the purpose of this facility arrangement is to allow a larger number of researchers to incorporate spectroscopic data into their ongoing research efforts. Use and scheduling of the laboratory is overseen by a RELAB advisory committee consisting of 3-5 users and the science manager. A RELAB Description and Users Manual is available and is sent to potential users. This manual summarizes telecommunication options for transfer of data after measurement (users do not necessarily need to be present).

b) Use of the RELAB by individual investigators includes science applications in both planetary and terrestrial studies. Topics have also included basic research in reflectance spectroscopy necessary to understand the complexities of how light interacts with natural materials. A data management system has been developed and implemented that relates RELAB spectra to a formatted catalogue of individual samples and their physical and chemical properties. The RELAB database now contains  $\sim 2594$  spectra plus 496 lunar spectra from J. Adams and 178 meteorite spectra from M. Gaffey obtained in the 1970's. The combined sample catalogue contains entries for 1741 samples and affiliated information. This lays the groundwork to easily locate spectra, samples, and the chemical and physical properties of materials measured in RELAB. New capabilities now exist to obtain bulk spectral properties from small areas on a thin-section. Correction factors are now available for the non-Lambertian behavior of the standard halon at high phase angles.

c) The largest RELAB activity will continue to be the acquisition of high quality laboratory data for NASA investigators. This includes maintenance and repair efforts as well as further development and management of the RELAB database and data analysis activities. RELAB instrumentation and analysis capabilities will be substantially expanded to meet the needs of the advanced sensor era through equipment funds provided by a private foundation in cost sharing with NASA and Brown. A FTIR instrument which can obtain continuous reflectance spectra from 0.45 to  $20\mu\text{m}$  will be installed and should be operational by Fall 1989.

d) Publications of research efforts are included in research proposals of individual investigators. RELAB has produced a Description and Users Manual that is made available to all investigators. It contains information on system capabilities, operations, data base management, digital data transfer, and useful data examples.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Address, Phone)

Dr. Carle M. Pieters  
Department of Geological Sciences  
Brown University  
Providence, RI 02912  
(401/863-2417)

TITLE:

Remote Sensing Information Applied to Geological  
Studies of Planets (NAWG-28)

ABSTRACT: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year; c. brief listing of what will be done this year as well as how and why; and d. recent publications relevant to the proposed work.

- a) Objectives: The central objectives of the research proposed here are to determine the composition of unexplored surfaces and to use this information to understand the geologic evolution of the planetary body. This program concentrates largely on the analysis of spectral reflectance measurements which provide information on mineral composition of unsampled surfaces. The reflectance experiment laboratory (RELAB) is used to measure spectral properties of planetary analogue materials under conditions comparable to remote measurements. Controlled experiments are performed to provide laboratory data necessary to develop analytical models and to understand the principles of how light interacts with geologic materials. A cornerstone of this program of geological studies of planetary surfaces is the integration of observational, laboratory, and theoretical investigations. Several diverse areas of research are included in this single proposal.
- b) Progress examples: Using craters as probes to the interior, analysis of reflectance data for the Moon reveals a crust with a very complex stratigraphy. Highland material excavated by the crater Bullialdus, for example, contains three distinct compositions, the upper two of which are gabbroic and the deeper unit noritic. Detailed analyses of the highly shocked Tsarev meteorite has been published and we have collected 23 regolith-related meteorites for similar studies. Although a variety of quantitative methods for analysis of absorption bands have been pursued, we have developed and successfully tested a significantly new approach for mathematical deconvolution of absorption features using a modified distribution model for electronic transition absorptions.
- c) Continuing tasks: (1) Analysis of spectroscopic data to understand the nature and evolution of the lunar crust. This includes derivation of quantitative compositional information, such as the composition of olivine at Copernicus. (2) Development and testing of analytical techniques for compositional information extraction. Emphasis will be on olivines and pyroxenes. (3) Regolith processes and information derived from the meteorite record. Emphasis is placed on identifying processes responsible for alteration the resulting spectral character of surface regoliths. Regolith development on Mars and the Moon will also continue to be explored. (4) Laboratory experiments and data analysis in support of planetary science objectives for the terrestrial planets. Continuous spectra will be obtained from 0.45 to 20  $\mu\text{m}$  using a newly installed FTIR spectrometer.
- d) Bibliography: Recent direct results from this grant include two full manuscripts and 9 diverse abstracts of work in progress (see attachments).



## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James B. Pollack  
(Name, Address, NASA Ames Research Center, M.S. 245-3  
Telephone Number) Moffett Field, CA 94035 (415) 694-5530

Co-INVESTIGATORS: Ted Roush  
(Name Only) \_\_\_\_\_

PROPOSAL TITLE: Studies of Surfaces and Rings

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) The purposes of the proposed research are to define the properties of solar system surfaces and rings and the processes that affect them. b) Recent accomplishments include: 1) Obtaining thermal emission spectra of Mars in the 5.4 to 10.5 micron spectral region and tentatively identifying features due to sulfates, carbonates and hydrates. 2) Defining the requirements for a sustained wet, warm climate on early Mars. 3) Estimating the mass fractions of water ice, hydrated minerals, and opaques on Callisto's surface. 4) Determining the wind stress pattern across the Martian surface with a general circulation model (GCM). 5) Characterizing the particle size distribution and spatial distribution of Saturn's F ring. c) During the next year, the following research is proposed: 1) Carrying out a detailed modeling of the Mars thermal emission spectra to further assess the identity of the feature-producing materials and establish abundances. 2) Analyzing Voyager images of Callisto to determine the spatial distribution of albedo units for use in modeling near IR spectra. 3) Performing an in-depth comparison of GCM wind stresses with aeolian features, including streaks. 4) Analyzing images of the shadow of the F ring on the satellite Epimetheus to bound this ring's inclination and thickness. d) Pollack, J.B., Kasting, J.F., Richardson, S.M. and Poliakov, K., (1987). The case for a wet, warm climate on early Mars. Icarus, 71, 203-224. Pollack, J., Dalton, B., Roush, T., Stoker, C., Witteborn, F., and Bregman, J. (1989). Airborne observations of Mars' thermal IR spectrum: evidence for sulfates, carbonates, and hydrates. Presented at 4th International Mars Conference. To be submitted to J. Geophys. Res.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James B. Pollack  
(Name, Address, NASA/Ames Research Center, MS 245-3  
Telephone Number) Moffett Field, CA 94035 (415) 694-5530

Co-INVESTIGATORS: Patrick Cassen, William Cabot and  
(Name Only) Kevin Thompson

PROPOSAL TITLE: Protostellar Disks and the Solar System

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) The purposes of the proposed research are to derive improved parameterizations of key physical processes operating in the solar nebula (e.g. turbulence), to model various stages in this accretion disk's development and evolution, and to derive observational constraints on the nature of the early solar system. These efforts are directed at constraining theories of the origin of planets and satellites. (b) Key recent accomplishments include: 1) conducting initial numerical simulations of turbulence for conditions relevant to the solar nebula; 2) constructing models of the solar nebula in which the inhibiting effects of low optical depth and the solar luminosity on thermal convection and disk evolution were simulated; 3) simulating the formation of a nebula disk from a collapsing cloud and examining its stability characteristics; 4) constraining the oxidation state, ice to rock ratio, and the C content of planetesimals in the outer solar nebula. (c) During the forthcoming year, we propose to: 1) continue our numerical simulations of turbulence with emphasis on the effects of rotational shear and including density stratification; 2) study the evolution of the solar nebula when it was tidally truncated by one or several giant planets; 3) simulate the exchange of angular momentum by gravitational torques between a rapidly rotating protosun and a nascent solar nebula; 4) conduct initial studies of the destruction of interstellar grains as they transit from an infalling molecular cloud into the forming solar nebula. (d) Cabot, W., Hubickyj, O., Pollack, J.B., Cassen, P., and Canuto, V. (1989). Direct numerical simulations of turbulent convection I. variable gravity and uniform rotation, submitted to Geophys. and Astrophys. Fluid Dyn.; Simonelli, D., Pollack, J.B., McKay, C.P., Reynolds, R.T., and Summers, A.L. (1989). The carbon budget in the outer solar system. Icarus, in press.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Dr. Carolyn Porco  
(Name, Address, Telephone Number) Lunar and Planetary Laboratory  
University of Arizona, Tucson, AZ 85721 (602) 621-2390

**Co-INVESTIGATORS:**  
(Name Only)

**PROPOSAL TITLE:**

Studies in Planetary Rings

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objective : i) Use Voyager data to study the relationships between spokes and other electromagnetic phenomena in the Saturn system; ii) Investigate the role played by spiral density wakes in the origin of the azimuthal brightness asymmetry in Saturn's A ring, and possibly the enhanced Voyager radio scattered signal received from Uranus'  $\epsilon$  ring.

b. Progress : i) Completed preliminary reduction of Voyager 1 images showing passage of spokes through Saturn's shadow on rings. Discovered that some spokes entering shadow emerge significantly enhanced in size and brightness, especially those within SKR-active sector of magnetic field. It appears that the imprinting of a new, radial spoke occurs in shadow. ii) Completed reduction of images for A ring brightness asymmetry study. Discovered that phase of brightness variation is invariant with respect to the observer, regardless of phase or emission angles, an observation not published before. Also, preliminary modelling results show that the asymmetry can be explained by density wakes of the type found by Julian and Toomre (1964) in explaining galactic structure; iii) Discovered that planetary acoustic oscillations may excite eccentricities in planetary rings; iv) Succeeded in obtaining Voyager images of solar system dust band region. Though dust bands were undetected, upper limit to the amount of fine material ( $\sim 1\mu$ ) in the bands has been determined.

c. Proposed work : i) Investigate further the nature and origin of the azimuthal asymmetry by using particle size and location (spiral wake) distributions appropriate to Saturn's rings and geometric ray tracing code to model this photometric effect as it is observed in Voyager imaging data. (In collaboration with Dr. Luke Dones of Ames Research Center and Dr. Alar Toomre of MIT.) iii) Complete observational and theoretical synthesis to understand connections between the SED's, the magnetic field and magnetosphere, and the creation/rejuvenation of spokes as they pass through Saturn's shadow.

d. Publications : Porco, C.C. (1988). *Eos, Trans. Am. Geophys. Union* 69,391.; Porco, C.C. (1989). *Advances in Space Research*. In press.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Names, Address,  
Telephone Number)

Frank M. Richter

Dept. of the Geophysical Sciences

Univ. of Chicago, Chicago, IL (312) 702-8102

CO-INVESTIGATORS:  
(Name Only)

Alfred Anderson

TITLE:

Studies for Lunar Magma-oceanography: Cumulate Dynamics

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

A. The long range goal of the proposed research is to develop governing equations and parameterizations for the chemical and dynamical processes that control crystal fractionation from a cooling magma system in order to address the formation and layering of the lunar crust. Topics to be studied both separately and combined include: (i) crystal settling (or floating) and post-cumulate compaction, (ii) convection in magma layers and within porous cumulates, (iii) assimilation and replenishment, and (iv) representations of phase equilibria and material properties of both crystals and melts as crystallization proceeds.

B. New proposal.

C. In the first year we will concentrate on modelling crystal settling (or floating) in an otherwise quiescent fluid (melt) over the entire range of crystal content from dilute, through hindered settling, to the final expulsion of interstitial melt by matrix deformation. Also in the first year we will develop the necessary representations of the phase equilibria and material properties of crystallizing basaltic melts.

D. Daines and Richter (1988) An experimental method for directly determining the interconnectivity in a partially molten system, Geophys. Res. Lett., v. 15, p. 1459-1462. Richter and Daly (1989) Dynamical and chemical effects of melting a heterogeneous source, (in press) JGR.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Carl Sagan, Lab. for Planetary Studies  
(Name, Address, Cornell University, Ithaca, NY 14853  
Telephone Number) (607) 255-4971

Co-INVESTIGATORS: Dr. Bishun N. Khare  
(Name Only) Dr. W. Reid Thompson

PROPOSAL TITLE: "Interdisciplinary Investigations of Comparative Planetology"

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a. A combination of laboratory studies to yield spectroscopic properties of residues of  $\text{H}_2\text{O}$ -hydrocarbon ices, and applications to radiation darkening of ices on satellites and the emission spectra of the organic grain component of comets. Studies of cometary impacts, survivability of organic components, and implications for the Earth, and a new numerical simulation of large impacts and chemical thermodynamic implications. Laboratory bidirectional spectroscopy of heated sulfur, and development and application of photoclinometric techniques to nonuniform-albedo cases.
- b. Analysis of infrared spectral properties of  $\text{CH}_4$  clathrate residues (Khare et al., 1989); further applications to the heliocentric evolution of cometary emission spectra (Chyba et al., 1989a); initiation of detailed treatment of cometary impacts and implications for organic delivery (Thomas et al., 1989); demonstration of destruction of organics by oxidants in the Martian subsurface and latitude dependence of oxidized depth (Chyba et al., 1989b); measurements of the bidirectional reflectance of heated sulfur; investigation of possible orbital dynamics and state for Triton (Jankowski et al., 1989); definition of constraints on the surface properties and haze optical depth of Triton by Vis-NIR spectral modeling, with implications for Voyager imaging (Thompson, 1989); survey and modeling of laboratory data relevant to radio/radar studies of Titan and icy saturnian satellites (Thompson and Squyres, 1989).
- c. New laboratory experiments on the time-course of albedo changes in electron-irradiated  $\text{CH}_4$  clathrate and  $\text{H}_2\text{O}$  ice containing other simple hydrocarbons; further applications of spectral properties of ice-irradiation organic residues to cometary emission spectra; completion of detailed studies of cometary impacts on the early Earth and contributions to the primordial organic inventory, including dense-atmosphere cases, and publication; extension of Martian oxidant diffusion work including effects of obliquity cycle, and publication; publication of Triton orbital evolution and Triton surface/haze light scattering papers; publication of heated sulfur bidirectional reflection study; extension of Io photoclinometry to nonuniform albedo using global classification basemaps; initiation of detailed study of impact processes for general cases using smoothed particle hydrodynamic method.
- d. Khare et al. (1989). Solid organic residues produced by irradiation of hydrocarbon-containing  $\text{H}_2\text{O}$  and  $\text{H}_2\text{O}/\text{NH}_3$  ices: Infrared spectroscopy and astronomical implications. *Icarus*, in press; Chyba et al. (1989). The heliocentric evolution of infrared cometary spectra: Results from an organic grain model. *Icarus*, in press; Thompson (1989). Triton: Constraints on the atmosphere and surface, attached, and other references above.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: John W. Salisbury  
(Name, Address, U.S. Geological Survey, MS 927  
Telephone Number) Reston, Virginia 22092 (703) 648-6382

Co-INVESTIGATORS: Roger Clark  
(Name Only)

PROPOSAL TITLE: Mid-Infrared Spectroscopic Investigation

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Growing interest in the thermal infrared has led to an infrared spectrometer or multispectral scanner planned for Mars Observer, EOS, and the Russian Vesta probe, and proposed for a lunar orbiter mission. Meanwhile, ground-based thermal infrared measurements are underway of Mercury, the Moon and asteroids. These developments show the need for both a library of thermal infrared spectral signatures of minerals and rocks and an understanding of the effects of different space environments on those spectral signatures to interpret current and future observational data. It is the purpose of this research to provide this needed capability.

b. This is a renewal proposal for research that during the past six months has resulted in publication of a library of the spectral signatures of solid and particulate igneous rocks, acceptance for publication in JGR of two papers interpreting data from this library for remote sensing applications, the measurement of chondrite and achondrite meteorite spectra, and the acquisition of comprehensive suites of metamorphic and sedimentary rocks for future characterization and measurement. We have also begun testing of a new portable field spectrometer.

c. During the coming year we will interpret and publish the library of meteorite spectra; and expand the measurement program to include metamorphic and sedimentary rocks, thus supporting current and future observational programs. We also will use the new field spectrometer to measure environmental effects on spectral emittance, comparing emittance spectra obtained under different conditions to ideal emittance.

d. Salisbury, J.W., Walter, L.S., and D'Aria, D., 1988, Mid-Infrared (2.5 to 13.5  $\mu$ m) Spectra of Igneous Rocks: USGS Open-File Report 88-686, 132 pp.

Salisbury, J.W., and Walter, L.S., 1989, Thermal infrared (2.5 to 13.5  $\mu$ m) spectroscopic remote sensing of igneous rock types on particulate planetary surfaces: Jour. of Geophysical Res. (in press).

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Gerald G. Schaber  
(Name, Address, Telephone Number) 2255 N. Gemini Dr., Flagstaff, AZ 86001  
602-527-7485; FTS 765-7485

**Co-INVESTIGATORS:** Richard Kozak  
(Name Only)

**PROPOSAL TITLE:** Geology and Tectonics of Venus

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objectives: Continue research on the geology, tectonics, and cratering history of Venus using Venera 15/16, PV (Pioneer Venus), and Earth-based radar data, integrating the results into Magellan targeting considerations and pre-Magellan geoscience workshops for NASA PGG planetary science investigators. Products anticipated include (1) 1:15,000,000-scale geologic and tectonic maps of north quarter of Venus (to be USGS Open File Reports, not to be formally published), (2) "terrain map" (1:25,000,000 scale) of the remainder of the Venusian surface observed only from Earth and PV, and (3) relevant journal papers describing aspects of regional and global volcanism, tectonism, and surface chronology.

b. Accomplishments: (Oct. 1, 1988-April 1, 1989): (1) Formal paper describing new evidence for global tectonic zones on Venus (Kozak and Schaber, 1989), (2) publication of abstracts describing the morphologies of ten Venusian shields between lat 30° and 90° N. (Schaber and Kozak, 1989) and of Clotho Tessera (Kozak, 1989), (3) considerable progress on compilation of a 1:15,000,000-scale geologic map of the Venusian north quarter; start of compilation of the tectonic map of the same regions.

c. Work Plan (April 1, 1989-Sept. 30, 1989): (1) Submit for publication (GRL) a paper on the morphologies of large Venusian shields; (2) submit for publication a major paper on Venusian tectonic processes; (3) continue research on Venusian "dome fields;" (4) complete 1:15,000,000-scale geologic and tectonic maps of Venus' north quarter as USGS Open File Reports; (5) continue research on regional and global aspects of Venusian geology, tectonics, and cratering history; (6) participate as organizers, conveners, and tutorial lecturers in the first Venus Geoscience Tutorial and Geologic Mapping Workshop to be held at USGS, Flagstaff on June 12-15, 1989.

d. Recent Publications: Kozak, R.C. and Schaber, G.G., 1989, New evidence for global tectonic zones on Venus, Geophys. Res. Letts., v. 16, no. 2, 175-178 (with cover stereopair based on Venera 15/16 and PV data).

## PROPOSAL SUMMARY

Principal Investigator: Robert M. Schmidt  
Boeing Aerospace Company Mail Stop 3H-29  
P.O. Box 3999, Seattle, WA 98124-2499  
(206) 657-3485

Co-Investigators: - - -

Title: Experimental Impact Cratering Mechanics

Abstract (a. overall objectives; b. accomplishments; c. proposed work; d. recent publications):

**a.** The overall objective for the three-year program underway is to develop the experimental techniques necessary to investigate cratering behavior in rock and to develop scaling relationships for large-body impacts onto planetary surfaces. The centrifuge technique and related shock physics experiments will be used to provide experimental data for relevant target materials of interest. With both powder and gas guns mounted on the rotor arm, it is possible to match various dimensionless similarity parameters, which have been shown to govern the behavior of large-scale impacts. The development of geotechnical centrifuge techniques has been pioneered by the principal investigator and is documented by numerous publications, the most recent of which are listed below.

**b.** Experiments have been conducted to investigate stress waveforms due to impact onto water as a preliminary analysis tool to the understanding of spallation in rock targets. The use of water allows photographic visualization of shockwave shapes including regions of tension which produce cavitation. A Barr and Stroud framing camera operating at one million pictures/sec was used to photograph the impact of an aluminum projectile onto water. In addition to the shock wave photographs, tests were conducted at two constant values of the coupling parameter. Results for peak stress from carbon gauge records show good agreement with the theory, when material wavespeed is included in the dimensional analysis.

**c.** All of the experimental techniques developed in our previous work are being extended to target materials of particular relevance and interest. For instance, at the depths associated with very large craters, geological materials are usually of low porosity. Target porosity has been shown to dramatically affect scaling. The proposed work will address energy coupling and size scaling for non-porous targets and will compare these results to previous studies involving porous targets as well as with scaling laws advocated by others in the literature. This will be accomplished by a variety of tests intended to isolate the effects of target density, porosity and friction angle on crater formation. In the case of rock, where size dependent target strengths are observed, methods to degrade rock by cracking and/or a "strengthless" simulant are being developed. This approach will allow determination of the gravity asymptote from which the appropriate scaling law for very large size impacts into rock can be obtained.

**d.** Schmidt R. M. and K.R.Housen (1987) Some recent advances in the scaling of impact and explosion craters, *Int. J. of Impact Engineering* 5, 543-560.

Holsapple K. A. and R. M. Schmidt (1987) Point-source solutions and coupling parameters in cratering mechanics, *J. Geophys. Res.*, 92(B7), 6350-6376.

Schmidt R. M., and M. E. Voss (1987) Shock measurement and visualization in water, *Proceedings of the Symposium on Techniques and Theory of Stress Measurement for Multi-Dimensional Shock Wave Applications*, ASME Publication AMD-Vol. 83.

Schmidt R. M. and H. E. Watson (1988) Impact-generated stress waves and spall in water (abstract), in *Lunar and Planetary Science XIX*, pp. 1031-1032, Lunar and Planetary Institute, Houston.

Schmidt R. M. and K.R.Housen (1988) Crater size estimates for large-body terrestrial impact (abstract), accepted for "Catastrophes in Earth History: Conference on Impacts, Volcanism and Mass Mortality", Snowbird, Utah.



## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Gerald Schubert  
(Name, Address, Dept. of Earth and Space Sciences  
Telephone Number) UCLA, 405 Hilgard Ave., L. A., CA 90024-1567  
(213) 825-4577

Co-INVESTIGATORS: Thermal and Dynamical Processes in the Evolution of  
(Name Only) Planets and Satellites

PROPOSAL TITLE:

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objective: Determine interior structures and thermal histories of planets and satellites. Relate surface tectonic features to mantle dynamics.

(b) Progress: Developed thermal history model of the Earth that includes degassing/regassing and the dependence of mantle viscosity on volatile content. Demonstrated that tidal heating in Enceladus could be a factor of 2000 greater than previous estimates. Found that the shape of Mimas is consistent with a variety of internal structures ranging from a silicate core surrounded by an ice shell, to a silicate-ice mixture throughout with a highly porous thin outer ice layer. Showed that tidal heating throughout Io's mantle leads to excess surface heat flow at Io's poles, while tidal heating in an asthenosphere leads to higher equatorial surface heat flow. Determined that solid friction in the Earth has been the main energy sink in the Earth-Moon tidal evolution with tidal dissipation in the oceans having a relatively small effect over geologic time (though it is important at present).

(c) Proposed Work: Develop thermal history models of Io's core and mantle to establish the feasibility of a present dynamo-generated magnetic field. Construct numerical models of mantle plumes with temperature-dependent viscosity. Apply the plume models to Mars and Venus to determine if major geologic features on these planets are associated with mantle plumes. Determine new parameterized convection models of Martian thermal history that account for early core formation, and uncertainties in the axial moment of inertia of Mars and in the planet's composition. Simulate the cooling history of the Martian core and investigate possibilities of magnetic field generation in Mars. Infer histories of crustal production and basaltic volcanism from the parameterized models.

(d) Summary bibliography: (6/88-3/89): 4 papers published, 5 papers in press, 2 papers submitted, 7 abstracts published, 9 oral presentations.

(e) Personnel: 1 faculty (part time), 2 graduate research assistants.

## PROPOSAL SUMMARY/ABSTRACT

Principal Investigator:  
(Name, Address,  
Telephone Number)

Peter H. Schultz  
Brown University  
Department of Geological Sciences  
Box 1846  
Providence, R.I. 02912  
(401) 863-2417

Co-Investigators:

Proposal Title: Planetary Impact Processes

Abstract:

a.) Objectives: 1.) To investigate the effects of an atmosphere on ejecta emplacement and cratering efficiency; 2.) To characterize impact vaporization; 3.) To explore the effects of impact angle on energy partitioning and magnetic-field generation; 4.) To understand the causes and possible applications of changes in crater shape and cratering efficiency observed in the laboratory and on the planets.

b.) Progress: Experiments, field studies, and analysis of planetary surfaces have provided the following results: 1.) Separation of the effects of atmospheric pressure, aerodynamic drag, and projectile-wake on cratering efficiency; 2.) Recognition of different styles of ejecta emplacement at Meteor Crater consistent with predictions from the laboratory; 3.) New estimates on the rate and style of erosion of the ejecta beyond 0.25 R from the rim at Meteor Crater; 4.) Identification of late epochs of high gradation rates on Mars; 5.) Quantitative estimates of impact-vaporization of volatile-rich targets as a function of impact angle; 6.) Recognition of possible signatures of impact vaporization on Mars; 7.) Preliminary assessment of conditions affecting projectile disruption following oblique impacts with implications for major terrestrial collisions; 8.) Initial characterization of impact-generated magnetic fields. 9.) Separation of factors affecting crater shape and scaling with applications to the planets; 10.) Constraints on the shape of transient impact cavities of basins from the style of volcanic and tectonic modification.

c.) Proposed Research: Laboratory experiments, terrestrial field studies, and analysis of the planetary surface record will be used to assess four broad areas: 1.) The effect of an atmosphere on cratering efficiency and ejecta emplacement styles through laboratory experiments (broad range of ejecta sizes, comparison of projectile wake effects with theory), continued field studies of Meteor Crater, Arizona, and applications to the emplacement and erosion of crater ejecta on the Earth, Mars, and Venus. 2.) Amount and style of vaporization as well as mixing of target and projectile from laboratory experiments with applications to icy satellites and cometary impacts. 3.) Processes controlling energy partitioning during oblique impacts will be explored through analysis and capture of projectile ricochet, projectile fragmentation, momentum transfer, and magnetic-probing of early-time processes. 4.) Parameters controlling crater shape and scaling through continued laboratory experiments, the planetary surface record, and the styles of basin modification.

d.) Summary Bibliography:

- Schultz, P.H. (1988) Impact Cratering on Mercury: A Relook. In *Mercury* (F. Vilas, C. Chapman, M.S. Mathews, Eds.), U. Arizona Press, pp. 274-355.  
Schultz, P.H. and Gault, D.E. (1989). Submitted to *Proc. Global Catastrophes*.  
Crawford, D.A. and Schultz, P.H. (1988). *Nature* 336, 50-52.  
Grizzaffi, P.A. and Schultz, P.H. (1989). *Icarus* 77, 358-381.  
Grant, J.A. and Schultz, P.H. (1989). *Icarus* (in revision).  
Wichman R. and Schultz, P.H. (1989). *J. Geophys. Res.* (in revision).

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** David H. Scott  
(Name, Address, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff,  
Telephone Number) (602) 527-7188 FTS 765-7188 AZ 86001

**Co-INVESTIGATORS:** Kenneth L. Tanaka  
(Name Only) Mary G. Chapman

**PROPOSAL TITLE:** Mars Elysium Basin: Water Volumetric Analysis and  
Water Sources

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a. Objectives and Justification: (1) To calculate the volume of water that filled the Elysium basin, one of the largest and most recent depositional basins on Mars. This basin is especially important for quantitative determinations of water volume, because it is the only known basin where direct evidence of a former high-water level can be obtained. (2) To map circumbasin materials and their channels that were water sources for the basin, and to estimate the amount of water supplied to the Elysium basin for comparison with data obtained from the first objective.
- b. Accomplishments: During the initial months of the first year (FY 89), tasks to complete both objectives have been pursued. Objective 1: (1) Viking images have been examined from 1at 25° N. to 15° S. and long 175° to 220°, and paleo-shorelines have been mapped. Objective 2: (1) four geologic maps at 1:2,000,000 scale are near completion; (2) channels and drainage areas have been mapped within the coordinates noted above.
- c. Work Plan: Objective 1, three tasks: (1) to extend the mapping of the perimeter of the paleolake shoreline from morphologic indicators out to long 157.5° and 247.5°; (2) in conjunction with task 1, to extrapolate from new topographic data the elevation of the spillpoints around the basin; (3) to calculate maximum water volume of the basin. Objective 2, four tasks: (1) to continue mapping, on six additional 1:2,000,000-scale maps (MC-8SW, 8NW, 16NW, 22NE, 23NE, 23NW), all members of the Medusae Fossae Formation and other circumbasin materials; (2) to extend the mapping of the distribution of channels and their drainage areas to long 157.5° and 247.5°; (3) to estimate the amount of water required to erode channels and the amount of water that may have been released by emplacement of the Medusae Fossae Formation; (4) to prepare geologic maps and data compilations for publication.
- d. Summary Bibliography:  
Scott, D.H., and Tanaka, K.L., 1986, Geologic map of the western equatorial region of Mars: U.S. Geol. Survey Misc. Inv. Series Map I-1802A.  
Scott, D.H., 1988, An unusual Martian channel (abs.): LPSC 19, p. 1047-1048.  
Tanaka, K.L., Chapman, M.G., and Scott, D.H., in press, Geologic map of the Elysium region of Mars: U.S. Geol. Survey Misc. Inv. Series Map I-xxxx, scale 1:5,000,000.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Name, Address,  
Telephone Number)

Dr. Virgil L. Sharpton

LPI - 3303 NASA Rd. 1, Houston, TX 77058  
713-486-2111

Co-INVESTIGATORS:  
(Name Only)

Kevin Burke, John W. Gibson

PROPOSAL TITLE:

A Geological and Geophysical Study of the Marquez Dome  
Impact Structure, East Texas

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. The newly recognized Marquez Dome structure is a well-preserved complex impact crater in East Texas. Its only known surface expression is an ~3 km wide circular exposure of central peak (Cretaceous cherts and marls) within the shallow marine sedimentary sequence of the Paleocene/Eocene Calvert Bluff Formation. Subsurface information indicate the crater is approximately 20 km in diameter. Occurrences of shattercones, breccias containing shocked quartz, and a shallow depth of deformation provide clear evidence of its impact origin. Because this feature was thought to be a salt structure, a wealth of geophysical and borehole have been collected over this structure. The proposed research project is intended as cooperative effort between LPI, University of Houston, and Chevron USA. The objectives of this project are (1) conduct field investigations of the exposures of central peak and search for exposures of other crater units; (2) locate and investigate the ejecta from this impact event in exposures of contemporaneous strata that extend from Louisiana to Mexico; (3) reprocess some of the more than 160 km of high resolution seismic data to enhance near surface returns.

b. New Proposal

c. Map the crater interior; enhance exposure by excavation; petrographic analysis of surface samples and of two existing cores that penetrate the central peak; reprocess and interpret 15 km of seismic data.

d. Gibson, J.W., and V.L. Sharpton, Marquez Dome: A newly recognized complex impact structure in East Texas, submitted to Spring 1989 Meeting of AGU, 1989 (Appendix 1). Sharpton, V.L., and D.C. Neilsen, Is the Bee Bluff Structure in S. Texas an impact structure?, Lunar and Planetary Science XIX, 1065-1066, 1988 (Appendix 2). Sharpton, V.L., Kevin Burke, L. Lucas, and F. Horz, Reflection seismic data from terrestrial impact structures: Evidence of shallow penetration? (abst), Papers presented at the 51st Annual Meeting of the Meteoritical Society, Fayetteville, Arkansas, p. D-4, 1988 (Appendix 3).

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Name, Address,  
Telephone Number)

Michael E. Sheridan  
Department of Geology  
Arizona State University  
Tempe, AZ 85287 - 1404 (602) 965-3760

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE: Ignimbrite emplacement and morphology on Mars

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. The principal objectives of this project are: (1) to catalog the major morphological and surface characteristics of terrestrial ignimbrites that can be distinguished at a resolution of 20 to 40 m per pixel visible on LANDSAT TM images, (2) to develop criteria for the identification of ignimbrite sheets on Mars, (3) to determine the morphologic features observed in areas of suspected Martian ignimbrites visible on high-resolution Viking images, (4) to apply multiple working hypotheses to resolve the origin of the Martian ignimbrite terrain, and (5) to contribute to the mapping of ignimbrite terrain in the 1:500,000 scale MTM program in cooperation with Dave Scott in Flagstaff. Because large areas of the Martian surface are covered with "ignimbrite" terrain, the correct identification and characterization of this material is significant. This is especially true because this material could be important as a site for future landing, sampling, or other scientific studies.

b. Because no funding has been received for this project, there are no results to report at this time.

c. All of the tasks in part (a) will be accomplished during this year.

d. Crown, D.A., Greeley, R., and Sheridan, M.F., 1988, Consideration of hydromagmatic origins for Hadriaca Patera and Tyrrhena Patera. Proceedings Lunar Science Conference XIX, p. Levine, A. and Sheridan, M.F., 1988, Spectral characteristics of ignimbrites: a Landsat view of the Bishop Tuff, California. American Geophysical Union, EOS, 69, p. 1507. Crown, D.A., Greeley, R., Sheridan, M.F., and Carrasco, R., 1988, The Frailes Formation, Bolivia: analysis of an ignimbrite plateau in the central Andes using LANDSAT Thematic Mapper data, American Geophysical Union, EOS, 69, p. 1507.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Eugene M. Shoemaker  
(Name, Address, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff,  
Telephone Number) (602) 527-7181; FTS 765-7181 86001

Co-INVESTIGATORS: Carolyn S. Shoemaker  
(Name Only)

PROPOSAL TITLE: Studies of Australian Impact Structures

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a. Objective: The objective of this study is to refine our understanding of the past flux of solid bodies in the neighborhood of the Earth. Australia is one of the most favorable regions of the world in which to find and identify impact structures; it contains 1/3 of the known young meteorite craters and the majority of Precambrian impact structures. Our specific goals are 1) to accurately document the cratering record of Australia, 2) to obtain precise ages of the impact structures, where possible, and 3) to search for evidence on the nature of the impactors, and 4) to use these results to reevaluate the flux history of terrestrial impacting bodies.
- b. Progress: Although this is a new proposal, the research proposed herein builds upon the results of a previous investigation (Impact Craters in Australia).
- c. Proposed work: In the first year, the principal effort will be to complete a monograph on the Australian impact structures. This book will contain an up-to-date account of all 19 impact sites now recognized. It will be based chiefly on the results of our five field seasons (including that of 1989), but it will also include chapters by other authors who have done the principal work on 8 of the sites. Our aim is to present thorough descriptions and geologic maps for nearly all of the known structures. Field work will be carried out to investigate (by geophysical methods) the subsurface structure of 4 meteorite craters and to acquire samples for studies of the erosional history of these craters.
- d. Bibliography:
- Shoemaker, E.M., 1983, Asteroid and comet bombardment of the Earth: Ann. Rev. Earth Planet. Sci., v. 11, p. 461-494.
- Shoemaker, E.M., and Wolfe, R.F., 1986, Mass extinctions, crater ages, and comet showers, in Smoluchowski, R., Bahcall, J.M., and Matthews, M., eds., The Galaxy and the Solar System: Tucson, Univ. of Arizona Press, p. 338-386.
- Shoemaker, E.M., and Shoemaker, C.S., 1988, Impact structures of Australia (1987) [extended abs.]: Lunar and Planetary Science XIX, p. 1079-1080.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Eugene M. Shoemaker  
(Name, Address, Telephone Number) 2255 N. Gemini Dr., Flagstaff, AZ 86001  
602-527-7181; FTS 765-7181

**Co-INVESTIGATORS:** Carolyn Shoemaker  
(Name Only) Ruth Wolfe

**PROPOSAL TITLE:** Chronology of Bombardment in the Solar System

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a. Objective: The broad objective of this investigation is to improve the cratering time scales for the terrestrial planets and to advance our understanding of the present and past flux of solid objects in the outer Solar System. Specific goals are to 1) reassess the asteroid and long-period comet flux in the terrestrial planet zone, 2) derive a more precise cratering time scale for Venus, 3) obtain a new estimate of the long-period comet flux at the orbit of Jupiter, 4) evaluate the fraction of periodic comets derived from the Oort cloud and reassess the population of Jupiter family comets, and 5) continue the assessment of the populations and dynamical structure of the L4 and L5 Trojan swarms, in order to refine estimates of planetesimal flux in early Solar System time.
- b. Progress: New Proposal
- c. Proposed Work: In the first year of this 3-year investigation, a new estimate of the population of Earth-crossing asteroids will be made by combining discoveries made in the Palomar Asteroid and Comet Survey (PACS) with results of earlier surveys. On the basis of this estimate, of new calculations of collision probability with Earth and Venus, and of the Phanerozoic cratering record of Earth, we will derive a refined cratering time scale for Venus. We will also evaluate the size distribution of Earth-crossing asteroids. Analysis of observations of long-period comets discovered in the PACS will be started in order to prepare a new estimate of the long-period comet flux out to the orbit of Jupiter. In addition, we will reduce available positional observations of Trojan asteroids discovered by the PACS in order to derive more secure orbits and expand knowledge of the dynamical structure of the L4 and L5 swarms.
- d. Bibliography: Schaber, G.G., Shoemaker, E.M., and Kozak, R.C., 1987, The surface age of Venus: Use of the terrestrial cratering record: Solar System Research, v. 21, p. 89-94. Shoemaker, E.M., Shoemaker, C.S., and Wolfe, R.F., 1988, Asteroid and comet flux in the neighborhood of the Earth [extended abs.]: Global Catastrophes in Earth History: An Interdisciplinary Conference on Impacts, Volcanism, and Mass Mortality, Lunar and Planetary Institute, Houston, Texas, p. 174-176. Shoemaker, E.M., Shoemaker, C.S., and Wolfe, R.F., in press, Trojan asteroids: populations, dynamical structure, and origin of the L4 and L5 swarms: in Asteroids II, R.P. Binzel and M.S. Matthews, eds., University of Arizona Press, 50 p.

## PROPOSAL SUMMARY

### PRINCIPAL INVESTIGATOR:

Robert B. Singer, Associate Professor  
Planetary Sciences Department  
Lunar and Planetary Laboratory  
University of Arizona  
Tucson, AZ 85721  
(602) 621 4573

### Composition and Distribution of Mars Surface Materials

#### ABSTRACT

**A. Objective** This is a full 3-year proposal for continuation of a longstanding research program to improve our geologic understanding of Mars. Emphasis is placed on mineralogy and distribution of surface materials at the present time, from which current processes and geologic history are inferred. Primary data used are existing earthbased spectral reflectance data and Viking multispectral images, with terrestrial remote-sensing data of Mars analog sites used as well. Laboratory studies and development of data analysis techniques will be conducted as required for the proposed science. We will continue to play a major role in closing the gap between image data and spectroscopic data.

**B. Progress** This is a new proposal. However, substantial results have been obtained under the predecessor grant NAGW-1059, and are reported in the attached Progress Report.

**C. Proposed Work** 1. Spectrophotometric Analysis of the Coprates quadrangle, utilizing overlapping Viking Orbiter multispectral coverage with differing incidence and emission angles. Hapke parameters (e.g. single-scattering albedo, macroscopic roughness) will be solved for and integrated into a geologic mapping procedure for compositional and physical properties. 2. New high-resolution spectral image data obtained during the 1988 opposition (under separate funding) will be analyzed for compositional and spatial variability of  $\text{Fe}^{3+}$ -bearing weathering products and  $\text{Fe}^{2+}$ -bearing pyroxenes. 3. Spectral-image investigation of basaltic pyroclastics and maar volcanism on Earth, for application to Mars remote-sensing and exploration. This task is coordinated with the NASA Geologic Remote Sensing Field Experiment. 4. Geologic investigation of scapolite on Mars, based on near-infrared telescopic data obtained in 1988 (under separate funding). These observations led to the discovery of scapolite on Mars, and contain considerable additional information about its occurrence, abundance, and possible modes of origin.

#### **D. Recent Publications:**

Nature and Distribution of Surficial Deposits in Chryse Planitia and Vicinity, Mars. R.E. Arvidson, M. Dale-Bannister, E.A. Guinness, J.B. Adams, M.O. Smith, P.R. Christensen, and R.B. Singer, *J. Geophys. Res.*, **94**, 1573-1587 (1989)

Spectral Imaging of Mars During the 1988 Apparition. R.B. Singer, E.S. Bus, K.W. Wells, and J.S. Miller, *4th Int'l Conference on Mars*, 185-186 (1989).

Valles Marineris: Compositional Constraints From Viking Multispectral Images. P.E. Geissler, R.B. Singer, B.K. Lucchitta, *4th Int'l Conference on Mars*, 111-112 (1989).

Discovery of Globally-Distributed Scapolite on Mars. R.N. Clark, R.B. Singer, G.A. Swayze, and A. Tokunaga, *4th Int'l Conference on Mars*, 82-83 (1989).



## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Laurence A. Soderblom  
(Name, Address, 2255 N. Gemini Dr., Flagstaff, AZ 86001  
Telephone Number) 602-527-7018; FTS 765-7018

Co-INVESTIGATORS: Alfred McEwen  
(Name Only)

PROPOSAL TITLE: Global Color and Surficial Geology of Mars

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objectives: Proposed is the generation and analysis of a new global digital colorimetric map of Mars based on Viking Orbiter images. The new map will have about 10 times higher resolution than the approach mosaic of Soderblom et al. (Soderblom, L.A., Edwards, Kathleen, Eliason, E.M., Sanchez, E.M., and Charette, M.P., 1978, Global color variations on the Martian surface; Icarus, 34, p. 446-464). The result will be about 100 times more information. The images to be used were acquired under ideal seasonal and better viewing and illumination conditions (the old database is obscured by clouds, fog, and frost). The scientific objectives are (1) to classify and map surficial units and (2) to study their geologic settings. We anticipate that the new database will be widely used by the planetary community. Its scientific applications go far beyond those proposed here, and it will be an important element in planning future exploration of Mars.

b. Progress: During the first two fiscal years (FY 88-89), we accomplished the following: (1) validation of radiometry, (2) introduction of refined geometric control, (3) validation of seam-suppression techniques, (4) completion of eight major regional mosaics covering 85% of Mars, (5) development of a fast procedure to apply a complex atmospheric scattering model to derive normal spectral albedo, and (6) major progress in development of numerical models to be employed in the photometric software system. Several abstracts were published and two journal papers are in preparation.

c. Work Plan FY 90: The following tasks are planned for the coming fiscal year: (1) completion of numerical modeling scheme for an anisotropic scattering atmosphere, (2) inclusion of complex surface scattering models, (3) application of these models to the radiometric databases in sinusoidal projection, (4) merging of the photometrically modeled mosaics into a global spectral photometric normal-albedo dataset, (5) completion of science analyses identifying mappable spectral units and preparation of final results for publication, (6) conversion of final mosaics and photometric models to CD-ROM format for publication and distribution to the planetary community.

d. Relevant Bibliography:  
McEwen, A., Soderblom, L., and Swann, J., in press, Color mosaics and surficial geology of Mars:  
Abstracts 1988 JGR Fall Mtg.

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PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Name, Address,  
Telephone Number)

Sean C. Solomon  
54-522, M.I.T.  
Cambridge, MA 02139 (617) 253-3786

CO-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE:

Tectonic History of the Terrestrial Planets

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal"; c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- 
- (a) Our broad goal is to understand the comparative tectonic, volcanic, and thermal histories of the terrestrial planets.
- (b) During the past year we obtained constraints on the crustal thickness and lithospheric thermal gradient on Venus from the extent of viscous relaxation of impact crater topographic relief, carried out tests of models of crustal divergence in the Venus equatorial highlands, estimated the lithospheric thermal gradient and heat flux on Venus from the elastic lithosphere thickness, and developed new models for the early thermal evolution of the terrestrial planets and meteorite parent bodies, including in particular the role of interior volatiles.
- (c) In the coming year our proposed work includes further development of mechanical and thermal models for the formation and evolution of Venus mountain belts; the application of viscous relaxation calculations to limit the mode of origin, age, and dynamics of highlands and coronae on Venus; the quantification of global patterns of tectonic deformation on Venus; the further investigation of lateral heterogeneity in lithospheric thermal gradients on the terrestrial planets from elastic flexure models; the development of finite element models of stress within and around large volcanic constructs to study the relation between volcanic processes and stress; and the systematic investigation of global thermal history models for the Moon and Venus.
- (d) Grimm, R.E., and S.C. Solomon, Viscous relaxation of impact crater relief on Venus: Constraints on crustal thickness and thermal gradient, *J. Geophys. Res.*, 93, 11911-11929, 1988.
- Grimm, R.E., and S.C. Solomon, Tests of crustal divergence models for Aphrodite Terra, Venus, *J. Geophys. Res.*, submitted, 1988.
-

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Paul D. Spudis  
**(Name, Address,** U.S. Geological Survey, Flagstaff, AZ 86001  
**Telephone Number)** 602-527-7482; FTS 765-7482

**Co-INVESTIGATORS:** P.A. Davis  
**(Name Only)**

**PROPOSAL TITLE:** Early Lunar Crustal Evolution

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) OBJECTIVES: To better understand early lunar crustal evolution, we will: 1) investigate the geologic context of exotic mare basalts at highland landing sites with the aim of more completely characterizing unvisited mare units; 2) use basin ejecta as probes of the lunar crust to understand lateral and vertical variations in crustal composition and structure; 3) determine the origin of low-K Fra Mauro basalt, a mixed lunar rock type of uncertain provenance; 4) estimate the global abundance of Al in the crust, to test the magma-ocean model of crustal origin; and 5) attempt to produce a petrologic map of the complete lunar near side through a combined remote-sensing mineralogical and geochemical approach.

b) PROGRESS: 1) Continued study of small mare basalt fragments from the highland Apollo 16 and Luna 20 landing sites. Chemical analyses of previously hand-picked fragments from the Apollo 16 Descartes core show that these rocks are highland impact melts, not mare basalts. 2) Completed studies of the lunar Nectaris and Crisium multi-ring basins. Results show pure anorthosite outcrops associated with Nectaris basin deposits and effects of initial target conditions on basin morphology by development of platform massifs. Completed manuscript of book "Geology of multi-ring basins", to be published by Cambridge University Press in 1990. 3) Completed initial studies of lunar LKFM impact melt 15445; results indicate clastic debris in the melt rock from at least two unidentified lunar rock types, one possibly gabbroic and the other possibly KREEP-rich. 4) Received and have started processing new multispectral image data for the central lunar highlands, to be used as the initial test area for our construction of a petrological map of the lunar near side.

c) PROPOSED WORK: 1) Complete analyses of mare basalts at Apollo 16 and Luna 20 and begin work on basalts from Apollo 14 site. Produce major synthesis on the volcanic history of the Moon, incorporating discoveries in lunar volcanism made since 1976. 2) Complete work on book manuscript for publication. Begin new study of lunar Humorum basin, including its geology, rings, and composition of deposits. 3) Complete study of Apollo 15 LKFM melt rocks by analyzing clasts in 15455. Begin study of Apollo 16 VHA basalt to determine provenance of clasts in this rock type, which is totally restricted to this site and may be melt ejecta from the Nectaris basin. 4) Assemble and mosaic imaging spectrometer data for entire "Apollo zone" of central near side and collate orbital chemical data. If possible, new mid-infrared spectra of lunar regions will be integrated into this effort.

d) SUMMARY BIBLIOGRAPHY (FY 1989): Spudis P.D., Hawke B.R., and Lucey P.G. (1989) Proc. Lunar Planet. Sci. 19, 51-59; McCormick K. et al. (1989) Proc. Lunar Planet. Sci. 19, 691-696; Spudis P.D. et al. (1989) Lunar Planet. Sci. XX, 1042-1043.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Steven W. Squyres  
(Name, Address, Space Sciences Bldg., Cornell University  
Telephone Number) (607) 255-3508

Co-INVESTIGATORS: Dr. Paul J. Thomas  
(Name Only)

PROPOSAL TITLE: "Geologic Studies of Mars and the Satellites  
of the Outer Planets"

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Objectives: We address a series of tasks, most of which are associated with Mars and the icy satellites of the outer planets: (1) We investigate the tidal and thermal history of Mercury; (2) We attempt to model the formation of coronae on Venus by mantle plumes; (3) We investigate the possibility that a significant fraction of the early terrestrial inventory of organic molecules were introduced by cometary impacts; (4) We attempt to understand the physical environment of perennially ice-covered lakes in the Dry Valleys of Antarctica and their relationship to early sedimentary environments on Mars; (5) We attempt to constrain models for the distribution of ground ice on Mars and (6) understand the extent to which oxidants have diffused into the martian regolith. (7) We model stresses within martian volcanoes to attempt to understand the origin of observed thrust faults on the flanks of several volcanic edifices; (8) We investigate the distribution and characteristics of ancient water-lain sediment on Mars; (9) We attempt to better understand ice deformation on the icy satellites and its effect on their geological histories; and (10) We investigate the dielectric properties of materials on icy satellites in the saturn system, and consider the implications of these properties for radar sounding.

(b) Progress: In the past year we (1) Determined likely despinning times for Mercury and examined the consequences for Mercury's geological evolution; (2) Constructed detailed numerical simulations for mantle plume-lithosphere interactions on Venus; (3) Constructed detailed simulations of aerobraking and impact physics for comets using several numerical simulation techniques; (4) Produced estimates of likely diffusion depths for oxidants on Mars for a range of physical conditions; (5) Constructed models for stresses within martian volcanoes; (6) Completed mapping of ancient sedimentation basins on Mars and modeled ice thickness on ice-covered martian lakes; (7) Developed a new model for palimpsest formation on Ganymede and (8) Demonstrated that long-wavelength radar sounding through a deep  $\text{CH}_4\text{-C}_2\text{H}_6\text{-N}_2$  ocean on Titan may be possible.

(c) Work Plan: In the coming year, we plan to (1) Complete the range of rheological models for Mercury; (2) Carry out a complete set of simulations of Venus mantle plume models; (3) Improve and complete our models for comet-atmosphere interactions and impact physics; (4) Complete models for martian oxidant diffusion; (5) extend our work on physical processes relevant to martian sediments and (6) Perform a quantitative statistical study of the morphology of relaxed terrain on Mars.

(d) Publications: S.W. Squyres, Urey Prize Lecture: Water on Mars. *Icarus*, in press. P.J. Thomas, S.W. Squyres and M.H. Carr, Flank tectonics of martian volcanoes, *J. Geophys. Res.* (submitted). (See Appendix B for others.)

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: David J. Stevenson  
(Name, Address, California Institute of Technology  
Telephone Number) Pasadena, California 91125  
818/356-0534

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE: Planetary Origin, Evolution and Structure

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a Theoretical work directed toward understanding the origin, evolution, and structure of planets and satellites.
- b (i) Interior models of Uranus have been constructed. These show that there is a fundamental ambiguity concerning the ice/rock ratio because rock-gas mixtures can mimic ice. The work also suggests that the low heatflow is caused by storage of primordial heat, possible because of compositional gradients. (ii) The IR spectra and thermal conditions of protostellar disks (e.g., T-Tauri) have been studied, with a view to understanding the temperature distribution in the disk, especially how it relates to interstellar and nebula grain size distributions. (iii) Work on formation of the Moon indicates that a single moon can arise from the aggregation of many small protoMoons, because of differential tidal evolution. The moon forms only partially molten, after  $\sim 10^3$  years, from a fragmented disk originally emplaced by impact. (iv) Models for extensional instabilities on icy satellites indicate that the grooves on Ganymede are not caused by these instabilities, but those on Enceladus could result from this mechanism. (v) Modeling of regolith annealing on large icy satellites indicates that the subregolith temperature is  $\sim 125$  K or less. Variation between equator and pole may affect the orientation of mantle convection in Ganymede and the possibility of polar wander.
- (c) (i) Accretion of the giant planets, with emphasis on the dependence on opacity. The aim is to understand when (if) an accretion disk forms, the origin of major satellites and the origin of giant planet rotation rates. (ii) The Neptune and Triton flybys are expected to stimulate work on the structures and evolutions of these bodies. (iii) Modeling of planetary volcanism, especially the relative amounts of intrusive and extrusive activity on Mars. This work will be based on recent advances in buoyancy-driven crack propagation. (iv) The earliest Earth, especially the freezing and differentiation of a primordial magma ocean. (v) Tidal heating models of Enceladus and Miranda. (vi) Fundamental modeling of ionic and metallic fluids at extreme pressures.
- (d) Twelve papers published or in press in the last 12 months, all supported by this grant. Five more in review. Two recent reprints, "Background Heatflow on Hotspot Planets: Io and Venus" and "Gravitational Instability in Two-Phase Disks and the Origin of the Moon" are appended to the proposal.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Glen R. Stewart  
(Name, Address, Telephone Number) LASP/U. of Colorado, Campus Box 392, Boulder, CO 80309  
(303) 492-3737

**Co-INVESTIGATORS:**  
(Name Only)

**PROPOSAL TITLE:** Kinetic Theory Models of Planetary Rings

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a) The overall objective is to determine the vertical structure of planetary rings that consist of a broad distribution of particle sizes. The goal is to develop a detailed model of the vertical structure, filling factor, velocity dispersions, and effective viscosity of observed rings and to provide the necessary dynamical input to constrain photometric models of Saturn's rings that are currently being developed by Dones, Showalter, and Cuzzi.
- b) This is a new proposal. Related research by the principal investigator in previous years has developed the theoretical framework for modeling multi-component planetary rings.
- c) Analytical approximations will be used to derive a tractable system of integral equations for ring structure from the kinetic theory of Araki and Tremaine. These equations are to be solved numerically for a realistically broad size distribution of ring particles, including the effects of large filling factor and self-gravity. Our approach is complementary to the n-body simulation approach being pursued by Wisdom, since our approach can treat broad size distributions with more modest computational resources.
- d) Stewart, G.R., D.N.C. Lin, and P. Bodenheimer, Collision-Induced Transport Processes in Planetary Rings, in Planetary Rings, R. Greenberg and A. Brahic eds., Arizona Press, 447-512, 1984. Shu, F.H. and G.R. Stewart, The Collisional Dynamics of Particulate Disks, Icarus, 62, 360-383, 1985. Brophy, T.G., G.R. Stewart, and L.W. Esposito, A Phase-Space Fluid Simulation of a Two-Component Narrow Planetary Ring: Particle Size Segregation, Edge Formation, and Spreading Rates, submitted to Icarus, 1989.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Robert G. Strom  
(Name, Address,  
Telephone Number) Dept. of Planetary Sciences  
University of Arizona  
Tucson, Arizona 85721  
(602) 621-2720

CO-INVESTIGATORS: S.K. Croft  
(Name Only)

TITLE: PLANETARY CRATERING INVESTIGATIONS AND  
ICY SATELLITE TECTONICS

This proposal consists of five tasks: Task 1) A study of the orbit dynamics of objects responsible for the late heavy bombardment of the terrestrial planets. Task 2) Recovery of the size distribution of impacting objects from the outer planet cratering record and impact crater mechanics. The objective of these two tasks is to constrain the origin of the objects responsible for impact cratering in the Solar System. Task 3) A study of layered terrain and closed canyons on Mars. The objective of this research is to understand Mars canyon formation and the associated depositional history. Task 4) A study of the tectonics and thermal evolution of icy satellites. The objective of this task is to understand the materials and mechanisms responsible for icy satellite evolution. Task 5) a carryover of a UDAP task on thermal evolution of uranian satellites (see Appendix B).

Progress Report: Task 1, initiated development of computer programs and preliminary simulations; Task 2, completed counts and positions of craters on Ganymede and initiated crater counts on Callisto to test leading/trailing asymmetries; Task 3 is a new task; Task 4, initiated investigation of ternary phase relations for a variety of possible components of icy satellites, and completed a crater depth/diameter study on icy satellites to constrain effective viscosities. Task 5, completed geologic maps and histories of the five major uranian satellites and estimated volumetric expansion of each.

Work Statement (1st Year): Task 1, complete development of computer programs and finish simulations for 5 orbit dynamical models of impacting objects. Task 2, complete crater counts on Callisto and leading/trailing asymmetry analysis to distinguish between crater populations internal and external to the jovian system. Task 3, determine distribution and morphologic classification of closed canyons and possibly related layered deposits, and initiate spectral analysis of canyon related deposits. Task 4, continue ternary phase relation analysis and continue development of thermal history models including magma migration and lithospheric failure. Task 5, thermal history modelling of uranian satellites continued from Uranus Data Analysis Program.

Summary Bibliography: 18 abstracts, 2 papers, 1 book chapter.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Kenneth Tanaka  
(Name, Address, Telephone Number) 2255 N. Gemini Dr., Flagstaff, AZ 86001  
602-527-7298; FTS 765-7298

**Co-INVESTIGATORS:** Mary Chapman  
(Name Only)

**PROPOSAL TITLE:** Geologic Maps of Parts of Kasei and Mangala Valles, Mars

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a. Objectives and Justification: The objective of this proposal is to produce interpretive detailed geologic maps of central Kasei Valles and north-central Mangala Valles. These maps will be at 1:500,000 scale, based on photomosaics MTM 25062, 25067, -05152, and -10152. The map areas have good to excellent image coverage. The investigators will apply image-processing and photoclinometry techniques to supplement standard photogeologic mapping. The map areas include features and relations illustrative of hydrologic conditions and provide clues to histories of exposed units. The maps will assist an established research project whose goal is to describe the development of unstable hydrologic conditions on Mars and the relation of these conditions to the evolution of such extensive channel systems as Kasei and Mangala Valles.
- b. Accomplishments: During the initial months of the first year of funding (FY 89), tasks to complete maps of both areas have been pursued. In the central Kasei Valles area, preliminary mapping of MTM 25062 has been completed. On January 14 and 15, we participated in a Mangala Valles workshop held by Ron Greeley at ASU. During the workshop, a consensus concerning names of stratigraphic units was reached by the various workers currently involved with the 1:500,000-scale maps of the region. In preparation for the meeting, we began preliminary mapping of MTM -05152 and -10152, north-central Mangala Valles.
- c. Work Plan for FY 89. To develop a cohesive stratigraphic history in the Mangala region, we need to produce our maps concurrently with other 1:500,000 scale maps of the same region. Therefore, it is necessary that we change the order of completion that was originally proposed. During the coming year (late FY89 - early FY90), we will complete the geologic maps of north-central Mangala Valles (MTM -05152 and -10152) rather than those of central Kasei Valles (MTM 25062 and 25067). Completion of the Kasei maps will be postponed until late FY90 and FY91.
- d. Summary Bibliography. Our recent publications pertinent to this project include MacKinnon D.J. and Tanaka K.L. (1988) Lunar Planet. Sci. Conf. XIX, pp. 707-708; Robinson M.S. and Tanaka K.L. (1987) Workshop on Nature and Composition of Surface Units on Mars, LPI, pp. 85-87; Tanaka K.L. (1988) Lunar Planet. Sci. Conf. XIX, pp. 1175-1176.



## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** Dr. Peter C. Thomas  
(Name, Address, 322 Space Sciences Bldg., Cornell University  
Telephone Number) Ithaca, NY 14853 607-255-9581

**Co-INVESTIGATORS:** \_\_\_\_\_  
(Name Only) "Studies of Morphologic and Surface Properties  
of Planets and Satellites"

**PROPOSAL TITLE:** \_\_\_\_\_

**ABSTRACT:** (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. Objectives. Study the properties and movement of surficial materials on Mars using Viking Orbiter color and albedo data, IRTM temperature data, and related morphologic data. Develop methods of useful disk resolved photometry of irregularly shaped satellites and asteroids and make physical inferences therefrom. Test significance of limb roughness data of satellites and asteroids by modelling effects of various physical processes on shapes. Determine shapes and limb topography of ellipsoidal satellites with unusual surface processes.

b. Progress. The investigation of regolith property effects on frost deposition has found a correlation of apparent deposit thickness and frost deposition timing; in combination with thermal inertia data this will help isolate compositional effects on frost nucleation/deposition. Determined the shape of Tethys which suggests differentiation and shows effects of tectonics on limb shapes. Begun mapping limb topography on Io of wavelength 30-100 km, and heights 1-8 km. Continued development of software for determining and mapping photometric properties of irregular satellites; continued work on modelling roughness transition diameters of asteroids and small satellites.

c. Work this year. Make map projected photomosaics of relation between dune frost and underlying colors and compare with IRTM data: study effects of polar layer exposures on frost retention. Use harmonic expansion shape of Phobos and test reasonableness of derived Hapke parameters. Compare simple models of limb roughness to progression of roughness observed for satellites. Finish limb study of Europa, Iapetus, and Enceladus.

d. Publications. One paper in press.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Name, Address,  
Telephone Number)

Thomas W. Thompson  
Jet Propulsion Laboratory  
(818) 354-3792 (FTS 792-3792)

TITLE:

Radar Studies of the Moon and Mars

### ABSTRACT

(a) Objective: The overall objective is geologic interpretation of radar measurements, including (i) analysis of the relation between landform identification and such characteristics of radar images as resolution, wavelength, and incidence angle; and (ii) establishment of constraints on lunar and martian near-surface structure at centimeter-to-decameter scales. These efforts support upcoming inner-planet missions scientifically (e.g., by improving interpretability of Magellan data via lunar analog images) and strategically (e.g., by providing information pertinent to Mars lander site selection).

(b) Progress: 1) Development of a Mars radar model consistent with the principal features of the Arecibo and Goldstone dual-polarization radar data sets. 2) Reduction of Arecibo 70-cm-wavelength data to yield unnormalized (i.e., uncalibrated), high-resolution (~1-km) images of Copernicus, Tycho, Plato, Aristarchus, and the Apollo 15 and 17 landing sites. 3) Reduction of Goldstone Mars radar data obtained in 1986, including estimation of Hagfors C parameters, circular polarization ratios, diffuse cross sections, and normal reflectances along various tropical subradar tracks.

(c) Proposed Work: 1) Extend existing Mars depolarized radar scattering model to the polarized (opposite sense circular, OC) S-band, 12.5 cm 1986 Goldstone observations as well as to the polarized, and depolarized X-band, 3.5 cm 1988 Goldstone observations. 2) Extend Arecibo high-resolution lunar mapping to new areas and complete reduction of the 1986 and 1987 Arecibo lunar observation.

(d) Recent Publications.

Crater Identification and Resolution in Lunar Radar Images, H. J. Moore and T. W. Thompson, (1988), Proceedings of the Eighteenth Lunar and Planetary Science Conference, Cambridge University Press, 383-395.

A Model for Martian Depolarized Radar Echoes, T. W. Thompson and H. J. Moore, (1989), Proceedings of the Nineteenth Lunar and Planetary Science Conference, 409-422.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: William C. Tittlemore, Assistant Professor  
(Name, Address, Dept of Planetary Sciences/LPL  
Telephone Number) Univ. of Arizona, Tucson, AZ 85721

CO-INVESTIGATORS: None  
(Name Only)

PROPOSAL TITLE: Dynamical Evolution in the Solar System

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- (a). We propose to investigate dynamical evolution in the solar system. The goal of these studies is to increase our understanding of the origin and evolution of the solar system and the objects within it. We will make use of the methods of modern nonlinear dynamics to address these complex dynamical problems.
- (b). FY 89 funding has not yet been received at the time of writing, therefore, we cannot report any progress under this scientific program. Nevertheless, because our research activities are supported in part by the University of Arizona, we have made significant progress in research areas relevant to this program. We have continued to study the dynamics of the Uranian satellite system, with particular attention to the effects on Miranda of passage through the 3:1 resonance with Umbriel. Numerical simulations of the evolution through this commensurability indicate that Miranda may have reached an orbital eccentricity of order 0.05 before escaping from the resonance, and tidal heating may have melted  $NH_3 \cdot H_2O$  deep in the interior of this satellite.
- (c). We will continue to carry out numerical and analytical studies of mean-motion commensurabilities among planetary satellites, in order to determine the effects of passage through resonances on satellite orbits and thermal histories. We will continue the investigation of mean-motion resonances in the Uranian satellite system, and extend the study to the satellite systems of Saturn and Jupiter. The stability of the solar system will be investigated, by studying the dynamics of few-planet solar systems. We will carry out an investigation of the dynamics of the Lagrangian satellites of Saturn, in order to determine the origin and explain the stability of these satellites.
- (d). Tittlemore, W. C. and J. Wisdom 1989. Tidal Evolution of the Uranian satellites. III. Evolution through the Miranda-Umbriel 3:1, Miranda-Ariel 5:3 and Ariel-Umbriel 2:1 mean-motion commensurabilities. Submitted to *Icarus*.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR:  
(Name, Address,  
Telephone Number)

Donald L. Turcotte  
Dept. of Geological Sciences, 4122 Snee Hall  
Cornell University, Ithaca, NY 14853-1504  
(607) 255-7282

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE:

Implications of Convection Within the Moon  
and the Terrestrial Planets

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a. The objective of the proposed research is to obtain a better understanding of geophysical and geochemical observations on the moon, Mars and Venus and to integrate this understanding with available observations on the earth. Planetary differentiation is a primary focus of the work. A variety of global geochemical cycles will be considered including major elements, trace elements, isotope ratios, and dissolved gases.

b. During the past year we developed a heat pipe mechanism for the transport of heat through the lithosphere of Venus. The heat pipe mechanism allows a relatively thick lithosphere on the planet that helps to explain the high observed topography and associated gravity anomalies. We also extended our studies of early thermal evolution and fractionation to Mars.

c. During the next year we propose to develop parameterized convection models for the thermal and chemical evolution of the moon Mercury, Mars, and Venus. The temperal crustal growth and volcanism will be compared with observations. Global geochemical cycles will be developed and compared with the available isotopic data.

d. D.L. Turcotte and G. Schubert, Radiogenic noble gases in planetary atmospheres, *Icarus* 74, 36-46 (1988); D.L. Turcotte, A heat-pipe mechanism for volcanism and tectonics on Venus, *Lunar Planet. Sci.* XIX, 1207-1208 (1988).

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: G. Leonard Tyler (415-723-3535)  
Center for Radar Astronomy (Durand Bldg - Room 232)  
Stanford Electronics Laboratories  
Stanford University  
Stanford, CA 94305-4055

ASSOCIATE INVESTIGATOR: Richard A. Simpson

### ABSTRACT:

(a) Overall Objectives: Radio wave scattering is an effective and important method for remotely studying planetary surfaces; on cloud covered bodies it is the *only* means by which surface mapping on a global scale can be carried out. The radio waves interact most strongly with surface structure having dimensions comparable to, and slightly larger than, the radio wavelength (centimeters to a few meters for modern radar systems). But it is precisely this scale range which has been most difficult for theorists to incorporate in their scattering models. As a result, interpretation today relies heavily on rather simple tools and concepts now more than twenty years old -- tools which are totally inadequate for explaining important phenomena such as high angle scattering and wavelength dependence. With missions such as Magellan on the near horizon, it is essential that we improve our interpretive base.

Recent advances in numerical techniques and computer technology, as well as some changes in analysis direction, offer the promise of new interpretive techniques. Numerical codes developed for scattering studies supported largely by the Departments of Defense and Energy are now becoming generally available. At the same time computers themselves are being improved to the point where those commonly available can handle the enormous arrays and millions of operations necessary to solve these problems. An early objective has been to survey the software available for numerical electromagnetics, obtain and convert those programs which seemed most promising for planetary applications, and test them on simple problems which have known (or easily derived) solutions. Our current and future objective is to develop surface models useful in the planetary context, apply the new tools, and compare the results with measurements and planetary data sets.

(b) Progress Report: We have acquired and adapted for use on our computer several software packages of varying complexity and application. No code is useful in a *wide* range of planetary problems; the Numerical Electromagnetic Code (NEC) appears to be the most promising. It calculates charges, currents, and radiation patterns from structures defined in terms of wires and/or surface patches. In its present form structures containing up to 300 elements may be analyzed. We have compared NEC results against analytical solutions for flat plates and perfect spheres and find good agreement. In fact, simplifications required to obtain the theoretical, closed-form solution for the plate suggest the NEC solution may be the more accurate. We have also computed and compared the scattering from a cube, cylinder, and sphere; for equivalent characteristic dimensions less than  $\lambda/10$  they become indistinguishable, nor can the orientation of a single object be determined. We are now beginning study of multiple objects, specifically to understand the coupling between them.

(c) Task Summary for First Year: We propose to continue testing and using NEC for scattering studies. This will include completion of study of the two-sphere problem and completion of a comparable "two mesh" problem, to simulate behavior of small surface fragments. Generalization of the program to remove the 300 element limit is also planned. We will continue involvement with the Geological Remote Sensing Field Experiment (GRSFE).

(d) Summary Bibliography: One abstract published in NASA TM

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Professor Joseph Veverka  
(Name, Address, 310 Space Sciences Building  
Telephone Number) Cornell University, Ithaca, NY 14853  
607-255-3507

Co-INVESTIGATORS:  
(Name Only) \_\_\_\_\_

PROPOSAL TITLE: "Physical Studies of Planetary and Satellite Surfaces"

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

**Aim:** Continue study of physical properties of planetary and satellite surfaces with emphasis on photometry, comparative morphology, and regolith processes.

### **Recent Progress**

- 1) Completed analysis of Voyager observations of Uranus' small satellites and published several studies on photometric properties of the larger Uranian satellites.
- 2) Completed detailed photometric study and albedo map of Rhea; determined Hapke parameters of snow/frost surfaces for comparison with icy satellites; showed that satellite frosts are very backscattering.
- 3) Established that average photometric roughness of Io is higher than that of lunar maria; compared daytime/nighttime albedo patterns on Io.
- 4) Completed several comprehensive review papers.

### **Proposed Work for Coming Year**

- 1) Determine photometric roughness of regions on Io.
- 2) Continue photometric studies of icy Saturn satellites aimed at elucidating backscattering behavior of frosts in outer solar system.
- 3) Characterize accurately the scattering behavior of frost on Ganymede and Callisto.
- 4) Continue varied small satellite studies (Phobos, Deimos, Nereid, etc.).
- 5) Complete photometric studies of large Uranian satellites and extend investigation to Triton.

### **Summary Bibliography**

Simonelli and Veverka (*Icarus* 74, 240-261).  
Veverka et al. (*Icarus* 78, 14-26), and 11 other papers listed in recent bibliography (p. 32).

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Professor Joseph Veverka  
(Name, Address, 310 Space Sciences, Cornell University  
Telephone Number) Ithaca, NY 14853 607-255-3507

Co-INVESTIGATORS: Dr. Paul Helfenstein  
(Name Only)

PROPOSAL TITLE: "Study of the Effects of Photometric Geometry  
on Spectral Reflectance Measurements"

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

### **OBJECTIVES:**

**General:** Investigate how spectrophotometric properties of planetary materials depend on photometric geometry by refining and applying radiative transfer theory to data obtained from 1) spacecraft and telescope observations of planetary surfaces; 2) goniometric studies of laboratory analogs, and 3) computer simulations. Assess physical interpretation of photometric parameters in the context of planetary surface geological properties and processes.

**Specific:** To further test and extend Hapke's photometric model; to apply the model to observations of planetary/satellite surfaces and to laboratory analogs.

### **PROGRESS DURING PAST YEAR:**

- 1) Completed study of uniqueness of Hapke parameters derived from groundbased observations of asteroids.
- 2) Completed investigation of connection between Hapke's roughness parameter  $\bar{\theta}$  and geologically defined terrain roughness.
- 3) Developed error analysis software for fitting Hapke's equation.
- 4) Developed simple  $(\bar{\omega}_0, g)$  mixing model and successfully applied to Saturn and Uranus satellite data.
- 5) Initiated study of how large-scale shadows are modified by multiple scattering.

### **SUMMARY OF PROPOSED RESEARCH:**

- 1) Develop improved macroscopic roughness correction to Hapke's model valid for surfaces of high albedo and/or large topographic relief.
  - 2) Perform goniometer measurements at high phase angles ( $>120^\circ$ ) to define most appropriate form of the particle phase function for use in Hapke's equation.
  - 3) Develop improved "mixing model." Perform laboratory measurements to test model and contrast results with predictions of Hapke's current "mixing model."
- SUMMARY BIBLIOGRAPHY:** Helfenstein (1988) *Icarus* 73, 462-481; Helfenstein et al. (1988) *Icarus* 74, 231-239; and six other papers listed in attached bibliography (p. 19).

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. William R. Ward  
(Name, address, tel. no.) Jet Propulsion Laboratory M/S 183-501  
4800 Oak Grove Drive, Pasadena, CA 91109  
(818) 354-2594

CO-INVESTIGATORS:  
(Name Only)

Title: Dynamical Studies of Solar System Formation and Evolution

ABSTRACT (Single-spaced, type within box below. Paragraphs numbered a-d should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year as well as how and why; and d. one or two of your recent publications relevant to the proposed work.):

A. Objective: Several dynamical studies are continued that promise to clarify or place constraints on certain aspects of solar system formation. (1) The nebula's density wave response to both Lindblad and corotation resonances is being calculated and explicit torque cut-off functions are being developed for both types of resonances. (2) Effects of bending wave torques on the orbital inclination of planetesimals and accreting planets is being examined. (3) Models of solar nebula dispersal in the presence of tidal flow barriers are under development. (4) Modifications in accretion growth rates due to density wave effects are to be incorporated in planet and satellite building models. (5) Three dimensional aspects of density wave propagation are to be modelled with particular emphasis on shock dissipation.

B. Progress: A paper calculating the torque cut-off function for corotation resonances has been published in Ap.J. A paper discussing the role of protoplanet migration in suppressing truncation of the nebula has been submitted to Ap.J. A third paper providing an overview of the role of density wave torques in the accretion process has been submitted to M.N.R.A.S. A fourth paper applying density wave theory to the formation of giant planet cores is near completion. A Chapter on Long-term orbital and spin dynamics of Mars has been completed for the upcoming book on Mars.

C. Work is under way on a calculation of the torque cut-off function for  $|l-m|$  Lindblad resonances. A paper discussing bending waves in the solar nebula is in revision. Work will continue on the role of tidal barriers during nebula dispersal. Work will begin on three dimensional modelling of density wave propagation.

D. Summary Bibliography: Ward, W.R. (1988) "Density waves and planetesimal dispersion velocities", in Abstracts of Conference on the origin of the earth, 96-97. Ward, W.R. (1989) "Corotation torques in the solar nebula: The cut-off function", Ap. J., in, 526-538. Ward, W.R. (1989) "Disc tides and the formation of giant planet cores", LPSC XX abstracts (in press).



March 1989  
Planetary Geology and Geophysics

**PROPOSAL SUMMARY**

**PRINCIPAL INVESTIGATOR:** Stephen G. Warren  
**(Name, Address,** Dept. of Atmospheric Sciences AK-40, Univ. of  
**Telephone Number)** Washington, Seattle, WA 98195. 206-543-7230

**Co-INVESTIGATORS:** Conway B. Leovy  
**(Name Only)** Optical properties of CO<sub>2</sub>-ice and CO<sub>2</sub>-snow in  
**PROPOSAL TITLE:** the visible and infrared

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) The spectral absorption coefficient of pure CO<sub>2</sub>-ice will be measured in the weakly-absorbing regions of the visible and infrared, 0.3-50  $\mu$ m wavelength. The planned advance over previous work is to revive a disused method for growing clear thick crystals of CO<sub>2</sub>. The spectral absorption coefficient is needed for understanding the reflection, absorption, transmission and emission of radiation by materials containing CO<sub>2</sub>-ice. We will use it to model the spectral albedo and emissivity of CO<sub>2</sub>-snow in the polar caps of Mars. This in turn we will use to determine a strategy for remote sensing of CO<sub>2</sub>-snow grain size, water-ice content, and dust content.

(b) The first year has not yet begun, so there are no accomplishments.

(c) The first-year's work will be the laboratory measurement of spectral absorption coefficient of CO<sub>2</sub>-ice in the visible and infrared, away from the strong bands, using laboratory facilities at Jet Propulsion Lab. In the second year we will complete the experimental work and begin the radiative transfer modeling as well as analysis of remote-sensing data.

(d) S. G. Warren, 1982: Optical properties of snow. Rev. Geophys. Space Phys., 20, 67-89.

S. G. Warren, 1986: Optical constants of carbon dioxide ice. Applied Optics, 25, 2650-2674.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Thomas R. Watters  
(Name, Address, National Air and Space Museum  
Telephone Number) Washington, D.C. 20560, (202) 357-1457

Co-INVESTIGATORS: Dr. Ted A. Maxwell  
(Name Only)

PROPOSAL TITLE: Analysis of Tectonic Features on the  
Terrestrial Planets

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) This proposal is for a 1-year continuation of NASA Grant NAGW-940 to investigate tectonic features on the terrestrial planets. The objectives of the proposed research are to formulate models for the origin of certain tectonic features based on detailed morphologic and structural analysis. Essential to the proposed research are field investigations of potential terrestrial analogs.

(b) During the the first months of the present funding year, work has been completed on the lineament mapping of known and suspected strike-slip faults in the deformed Columbia River basalts. The system of tectonic features (i.e., first-order anticlines and strike-slip faults) and their geometry are consistent with a pure shear mechanism. The mapping and analysis of the structures in the floor of the Olympus Mons caldera have been initiated and the modeling phase is planned for the latter part of this funding year. The study of wrinkle ridge-upland scarp associations will also be initiated this year.

(c) In the second year of the grant the following will be accomplished: 1) the study of wrinkle ridge-fault scarp associations on the Moon and Mars will be completed and kinematic and mechanical models for their origin finalized; 2) a two week field study of structures on the Columbia Plateau that may serve as terrestrial analogs to second-order ridges and wrinkle ridge-fault scarp associations on the Moon and Mars.

(d) Watters, T.R., Periodically spaced ridges of the Columbia Plateau, in Volcanism and tectonism in the Columbia River flood-basalt province, Geol. Soc. Am., Special Paper 239, edited by S.P. Reidel and P.R. Hooper, in press, 1989.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Stuart J. Weidenschilling  
(Name, Address, Planetary Science Institute  
Telephone Number) 2030 E. Speedway #201, Tucson, AZ 85719  
(602) 881-0332

Co-INVESTIGATORS: Donald R. Davis  
(Name Only)

PROPOSAL TITLE: Aerodynamic and Gasdynamic Effects in Cosmogony

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) The goal of this program is to understand the role of aerodynamic and gas-dynamic phenomena in the formation of the planetary system from the primitive solar nebula. Its scope includes interactions of the nebular gas and bodies ranging in size from dust grains to protoplanets.

(b) We have carried out numerical simulations of coagulation and settling in the solar nebula for dust aggregates having fractal properties. We determined that the longer settling timescales, compared with compact particles, are due to increased effectiveness of thermal Brownian coagulation relative to differential settling. We examined radial transport of solid matter due to gas drag during the early stages of planetesimal accretion and implications for the radially zoned structure of the asteroid belt.

(c) We will determine effects of nebular temperature and turbulence on the settling and growth of fractal aggregates in the solar nebula, to see whether a realistic set of parameters can produce preferred sizes in the range required for some models of chondrule formation. We will investigate properties of interior resonances between planetesimals and planetary embryos in the presence of gas drag, and the analogous phenomenon of interplanetary dust particles evolving by P-R drag.

(d) Physics of planetesimal formation, S.J. Weidenschilling, B. Donn, and P. Meakin, in Formation and Evolution of Planetary Systems, H. Weaver et al., Eds., Cambridge Univ. Press (1989).  
Fractal aggregates and planetesimal formation, BAAS 20, 815 (1988).  
Radial mixing of material in the asteroidal zone, T.V. Ruzmaikina, V.S. Safronov, and S.J. Weidenschilling, in Asteroids II, R.P. Binzel et al., Eds., U. of Arizona Press (1989).

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: STUART J. WEIDENSCHILLING  
(Name, Address, Planetary Science Institute  
Telephone Number) 2030 E. Speedway Suite 201  
Tucson, AZ 85719 (602) 881-0332

Co-INVESTIGATORS: Dr. Dominique Spaute  
(Name Only) Dr. Donald R. Davis

PROPOSAL TITLE: ACCRETION AND EVOLUTION OF SOLAR SYSTEM BODIES

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a) Goals: The purpose of this research program is to study physical and dynamical processes involved in the formation of the planets and smaller bodies in the solar system, using analytic and numerical techniques. The focus of the present proposal is the use of a new numerical simulation code to model the accretional evolution of a planetesimal swarm interacting over a range of heliocentric distances.
- b) Recent Progress: We have improved our numerical code and tested it against an analytic coagulation problem to demonstrate its validity and to optimize the choice of parameters. We developed an improved formalism for modeling the effects of long-range gravitational perturbations by bodies in non-crossing orbits.
- c) Proposed Research: We propose a three-year program to model numerically the accretion of planetesimals in the inner and outer parts of the solar system. We will use our spatially resolved multi-zone code to investigate phenomena of runaway growth of planetary embryos, dynamical isolation of feeding zones, radial transport by drag-induced orbital decay, long-range perturbations, resonances, and related phenomena. This work will be applied to accretion in the terrestrial planet zone in the absence of nebular gas, and to both the terrestrial and outer planet zones in the presence of gas.
- d) Summary Bibliography: Planetary accretion by runaway growth: Implications for asteroid formation, C. Patterson and D. Spaute, Icarus, submitted. Stirring of a planetesimal swarm: The role of distant encounters, S.J. Weidenschilling, Icarus, in press. Multizone accretional evolution of planetesimal swarms, D. Spaute, D.R. Davis, S.J. Weidenschilling, Adv. Space Res., in press.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Paul R. Weissman  
(Name, Address, Jet Propulsion Laboratory Mail stop 183-601  
Telephone Number) 4800 Oak Grove Drive Pasadena, CA 91109  
(818) 354-2636 FTS 792-2636

Co-INVESTIGATORS:  
(Name Only)

None

PROPOSAL TITLE:

Cometary Physics and Dynamics

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a. Physical and dynamical studies of comets are important to studies of the origin and evolution of the solar system, of the role of comets in supplying the volatile inventories of the terrestrial planets, of the role of comet vs. asteroid impacts on the Earth in initiating biological extinctions, and in planning for future NASA missions to comets. This task uses a variety of modeling techniques to perform computer based studies of the dynamics of comets in the Oort cloud and the thermal evolution of cometary nuclei, comparing results to observations wherever possible.
- b. Using the new mass estimates for cometary nuclei derived previously, new estimates of the cratering rate on the Earth have been derived. The steady-state flux of long and short-period comets provide 11% of the craters > 10 km diameter. The largest contribution, however, is from infrequent but massive, random comet showers, accounting for 26% of the cratering. Adding in the expected cratering from asteroids, the total predicted rate is comparable to that found from counting known craters on dated surfaces. A study of the anomalous brightness of Comet Halley at large solar distances was begun; it is suggested that the greater post-perihelion brightness beyond 3 AU is due to outgassing from large particles around the nucleus, ejected near perihelion. A search for evidence in IRAS data of Oort clouds around other stars (in collaboration with Alan Stern) has yielded only one likely candidate, but most Oort clouds are expected to be below the detection limit of IRAS. Estimates of cratering rates in the Pluto-Charon system show that impacts come primarily from Kuiper belt comets; estimates of a total mass of comets of 0.05 Earth masses in the Kuiper belt do not violate the very low eccentricity of Charon's orbit.
- c. In the coming year, work will continue on the modeling of Halley brightness at large solar distances in an attempt to understand the large particle environment around this comet. Dynamical studies will concentrate on development of a new Oort cloud dynamical program including the effects of stars, GMC's and galactic tides. In addition, thermal modeling of comets Kopff and Wild 2 in support of the CRAF mission will be undertaken.
- d. Weissman, P. R., A'Hearn, M. F., McFadden, L. A., and Rickman, H. 1989, Evolution of comets into asteroids, in Asteroids II, Univ. Arizona Press, in press. Weissman, P. R. 1989, The cometary impactor flux at the Earth, in Proceedings of the Conference on Global Catastrophes in Earth History, GSA Special Paper, submitted.

## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:** George W. Wetherill  
(Name, Address, Telephone Number) Department of Terrestrial Magnetism  
Carnegie Institution of Washington  
5241 Broad Branch Road, N.W., Washington, D.C. 20015  
(202) 686-4370

**Co-INVESTIGATORS:** NONE  
(Name Only)

**PROPOSAL TITLE:** Accumulation of the Planets

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

- a. Numerical and theoretical problems of planetary system formation are being investigated. The long range goal of this work, complemented by work elsewhere, is to develop quantitative internally consistent models of planetary formation that can be compared with observational data. During the proposed grant period, particular attention will be given to the accumulation of the asteroids, their fragmentation and loss, the evolution of planetesimals between the Earth and the asteroid belt, including Mars, and the influence of phenomena in these regions on the early history of Earth, Venus, and Mercury.
- b. (1) Concentrated on question of removal of material from region between Earth and  $\sim 2.35$  A.U., by approximate introduction of effects of spiral density wave drag, and outer planet commensurability and secular resonances in this region.
- (2) By use of about 200 new simulations of planetary growth studied the combined effects of these and other processes on the growth of planets interior to 2.35 A.U.
- (3) Extended previous work on formation and early fragmentation history of asteroid belt and began development of an improved program for treatment of asteroidal fragmentation.
- c. (1) Complete an investigation of a wide range of physical processes on growth of bodies interior to 2.35 A.U.
- (2) Continue study of growth and early fragmentation of asteroid belt, directed toward relating asteroidal history to the meteoritic record and to the geochemistry of the terrestrial planets.
- d. Wetherill, G. W., Formation of the Terrestrial Planets from Planetesimals, Proceedings of Workshop on Planetary Science, sponsored by the U.S. National Academy of Sciences - U.S.S.R. Academy of Sciences, Moscow, January 1989, in press, 1989.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. Fred L. Whipple  
(Name, Address, Smithsonian Institution Astrophysical Observatory  
Telephone Number) 60 Garden Street, Cambridge, MA 02138  
(617)495-7200 or FTS 830-7200

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE: Study of the Physics of Cometary Nuclei

ABSTRACT: (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

(a) Problems of the genesis and geriatrics of comets along with the problems of environmental and dimensional effects have been of major interest in cometary studies. The many observations of many comets by many observers using a variety of techniques, now provide a broad base for statistical analyses of the above problems. Are there any differences in the basic structures of individual comets after effects of environment, size, and aging are allowed for? Are there statistical differences among longer period comets depending upon the orientation of their orbits or the direction from which they came from Oort's cloud? These are the types of questions that the writer is investigating from the huge fund of cometary observations and calculations now available.

(b) For example, the orbits of Halley's Comet, C/Kohoutek (1973 XII), the unusual C/Morehouse (1908 III), the Kreutz sun-grazing family and several "great" comets are oriented towards a concentration of orbits near the direction of the galactic center and the Sun's Way. Is there a dynamic or genetic meaning to this concentration or is it simple coincidence?

(c) Studies of the shape, size, and activity of Halley's comet continue.

(d) "Active Polar Region on the Nucleus of Halley's Comet" (with H. J. Reitsema and W. A. Delamere), Science, 241, 198-200.

"A Model for intensity profiles of Dust Jets near the Nucleus of Comet Halley" (with W. F. Huebner, D. C. Boyce, H. J. Reitsema and W. A. Delamere) 1988, Icarus, 76, 78-88.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Dr. J.L. WHITFORD-STARK  
DEPARTMENT OF GEOLOGY  
SUL ROSS STATE UNIVERSITY  
ALPINE TX 79832  
(915) 837-8083

TITLE: PHOTOGEOLOGY AND REMOTE SENSING SYNTHESIS OF LUNAR MARE  
STRATIGRAPHY AND ERUPTION ENVIRONMENTS

### ABSTRACT:

- 
- A) This new proposal has six objectives: 1) To critically assess the similarities and differences between volcanic materials in each of the circular mare, irregular mare, and extra-mare tectonic environments. 2) To determine whether Pieters' map of the different volcanic spectral units can be updated in the light of new laboratory analyses of returned rocks, new spectral data, and more detailed geological mapping. If such is the case, modifications to the map will be made. 3) To synthesize the available information concerning the temporal compositional relationships for each of the three tectonic environments outlined in (1). 4) To correlate the lithostratigraphic units of the individual mare with the time-stratigraphic units recently summarized by Wilhelms (1987). 5) To provide chemical and age restraints for the volcanological processes that have taken place on the lunar surface. 6) To more clearly delineate the numbers and types of eruption sites by the construction of a computer database containing information about the location, dimensions, composition and age of each of the over 1,200 vents.
- B) New proposal.
- C) Work to be performed this year includes the completion of manuscripts on the Mare Frigoris and Mare Fecunditatis regions of the Moon and the initiation of the synthesis of all available data concerning the evolution of the lunar maria. This work will be accomplished through geological mapping of earth-based and orbital lunar photographs supplemented by spectral information in the form of spectral vidicon imagery and spectral data for individual sites. This will be further supplemented by other relevant published geochemical and geophysical data. A research student will be involved in the construction of the lunar volcano database.
- D) Some recent relevant publications are Whitford-Stark, J.L. 1987 Geol.Soc.Amer.Special Paper 213, 74pp. and Whitford-Stark, J.L. 1983 Advances in Planetary Geology NASA-TM p.127-353. Others can be found in Appendix 1.
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## PROPOSAL SUMMARY

**PRINCIPAL INVESTIGATOR:**

James G. Williams  
JPL, 238-332  
Pasadena, CA 91109  
(818) 354-6466, FTS 792-6466

**CO-INVESTIGATOR:**

James Gibson

**TITLE:** Solar System Dynamics -- Asteroids, Comets, and the Moon

**Objectives:** 1) Discover, define, and study asteroid families, the fragments of former collisions, to examine the interiors of former parent bodies. Physical properties data indicate the degree of differentiation of the parent body. Size and (imperfect) velocity distributions may be recovered. 2) Theoretical studies of the dynamical evolution of the solar system aid understanding. For example, improvements in the secular perturbations calculations permit new families to be recognized and old ones to be refined. 3) CCD images and Palomar Schmidt photographs provide positions of comets and minor planets which need further positions for the determination of accurate orbits. The observation program is separately funded. 4) The analysis of lunar laser ranges gives information on the lunar harmonics, moments of inertia, Love number, and dissipation.

**Progress:** This progress report covers 8 months. 1) A cooperative effort with other scientists using albedos and photometric colors finds 11 taxonomic groupings for asteroids. A paper has been published. 2) For the Asteroids II book a review (Identification of Asteroid Dynamical Families) has been submitted. 3) A methodical study of the geometry and taxonomy of families is 50% done. 4) A program has been constructed for the computation of short period perturbations. 5) Astrometric positions were published for 5 comets, 8 planet crossers, a Hilda, and a high inclination object. 6) A new program for numerically integrated lunar physical librations is complete and a program for integrated partials is well along.

**Proposed Work:** 1) Families will continue to be classified by morphological type. Physical properties data will be associated with the individual families. 2) A paper on the Alexandra family will be submitted for publication. 3) The taxonomy work will now be extended to the data of lower quality. 4) Theoretical work will be done as needed. 5) The astrometry program will continue to measure positions of comets and unusual asteroids, e.g. planet crossers, Trojans, Hildas, members of rare families, and high inclination objects. 5) Lunar laser data will be processed to determine lunar gravity field, Love number, and dissipation.

**Summary Bibliography:** 1) 1 paper published, 3 in press. 2 abstracts published. 1 poster presentation. 2) Astrometric positions are published in the Minor Planet Circulars.

# PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: Professor Jack Wisdom

Department of Earth, Atmospheric,  
and Planetary Sciences  
Massachusetts Institute of Technology  
Cambridge, Massachusetts  
(617) 253-7730

PROPOSAL TITLE: Solar System Dynamics

## ABSTRACT:

(a) We propose to continue our investigations of important dynamical processes in the solar system. Our goal is to gain a better understanding of the dynamics of the solar system and the processes which have shaped it, particularly in the light of recent advances in non-linear dynamical systems.

(b) We have made significant contributions to a wide variety of problems in planetary dynamics. Highlights of these contributions include: (1) the successful prediction of the chaotic rotation of Hyperion, (2) the discovery that all irregularly shaped satellites must tumble chaotically as they tidally evolve into synchronous rotation, (3) the establishment that the principal Kirkwood gaps in the asteroid belt are associated with chaotic zones in the phase space, (4) the demonstration that trajectories at the 3:1 chaotic zone have the necessary properties to transport meteoritic material from the asteroid belt to Earth, (5) the discovery of "adiabatic chaos" as a mechanism for producing large-scale chaos, and the introduction of a two-timescale method for predicting the extent and shape of chaotic zones, (6) the demonstration that the mean-motion commensurabilities among the Uranian satellites are associated with significant chaotic zones, (7) the demonstration that passage through the 3:1 Miranda-Umbriel resonance explains the anomalously large inclination of Miranda, (8) our systematic study of the passage of the Uranian satellites through orbital resonances allows us to place significant constraints on the rate of tidal dissipation in Uranus, (9) our long-term calculations of the evolution of the outer planets demonstrated that analytic theories of solar system motion were inadequate, and (10) our 845 million year integration of the outer planets indicated that the long-term evolution of the planet Pluto is chaotic.

(c) We shall continue our investigations of the dynamics of the solar system, using the same pioneering techniques we have used in our earlier studies. We shall carry out further studies of tidal evolution of natural satellite systems through resonance. We intend to extend the range of applicability of our work on the rotational dynamics of irregularly shaped satellites to the rest of the satellites in the solar system. Numerical investigation of the long-term evolution of the solar system and of small bodies in the solar system will be continued. Qualitative investigation of the stability of small solar systems will be continued, with emphasis on gaining a qualitative understanding of the Sun-Jupiter-Saturn phase space.

(d) Wisdom, J. (1987) "Urey Prize Lecture: Chaotic Dynamics in the Solar System." *Icarus*, **72**, 241.

Sussman, G.J. and Wisdom, J. (1988). "Numerical Evidence that the Motion of Pluto is Chaotic," *Science*, **241**, 433.

Tittemore, W.C., and Wisdom, J. (1988). "Tidal Evolution of the Uranian Satellites. Part II: An Explanation of the Anomalous Inclination of Miranda," submitted to *Icarus*.

## PROPOSAL SUMMARY

TITLE:     Dynamical Studies of Planets, Planetary Satellites and Asteroids

PRINCIPAL INVESTIGATOR: Charles F. Yoder  
INSTITUTION: Jet Propulsion Laboratory

CO-INVESTIGATORS:  
(name only)

### ABSTRACT

(a) overall objectives and justification of the work; (b) progress and accomplishments of the prior year, or "new proposal"; (c) brief listing of what will be done this year, as well as how and why; (d) bibliography

A. The basic objective of this research is to use dynamical arguments to obtain constraints on the origin and present states of planets, asteroids and planetary satellites. The principal emphasis shall continue to center on my study of orbit-orbit, spin-orbit resonance locks and tidal heating mechanisms. This proposal requests increased funding level.

B. The paper describing the fit of Voyager and ground-based data was submitted for publication. A libration theory for Phobos was completed (with N. Borderies). Phobos libration in longitude was found to influence the precession of the orbital periapsis position and may explain a discrepancy in orbital models. The contribution of Phobos topography to its gravity field was estimated.

C. Dynamical mechanisms related to the formation of the coorbital pair, Janus and Epimetheus shall be examined. Several studies related to Phobos orbital dynamics, librations, gravity field and their relationship to Phobos origin shall be continued. The constraint imposed by Mars precession constant on its internal structure shall be explored. The study of tidal history of the lunar orbit which includes significant lunar dissipation shall be completed. Lunar dissipation results from core-mantle friction due to precession of the lunar figure and causes a large change in lunar orbit inclination over time.

D. Yoder, C.F. et. al. (1983). Theory of motion of Saturn's coorbiting satellites, Icarus 53, 431; Salo, H. and C.F. Yoder (1988). The Dynamics of coorbital satellite systems, Astron. Astrophys., 202, 309-327.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: James R. Zimbelman  
(Name, Address, CEPS, National Air and Space Museum  
Telephone Number) Smithsonian Institution, Wash., D.C. 20560  
(202) 357-1424

Co-INVESTIGATORS:  
(Name Only)

PROPOSAL TITLE: Modification Processes and Extent of Bedrock Exposure  
in the Cratered Highlands of Mars

ABSTRACT: (Type single-spaced within box below. Paragraphs numbered (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

a) Objectives: 1) Identify the areal abundance and state of degradation of discrete surface units within the martian cratered highlands; 2) Establish constraints on the physical properties of the highland materials through a synthesis of high resolution data at visual, thermal infrared, and radar wavelengths; 3) Estimate the relative exposure of bedrock within individual units based upon the visible history of surface modification and the physical properties of the surface materials.

b) New proposal.

c) Proposed Work: In the Sinus Meridiani study area (15°N to 15°S, 330° to 360°W), 1) Identify geologic components present using high resolution (<30 m/pixel) images, particularly at locations where multiple layers may be present; 2) Determine the visual reflectance, thermal infrared emission, radar-derived slope characteristics for each unit; 3) Synthesize the results to constrain modification processes active on each unit; 4) Estimate the relative exposure of bedrock within each unit from infrared spectral properties and the geomorphic features associated with surface modification. On lava flows near Mana on Mauna Kea, 1) Measure the soil thickness on the flows; 2) quantify flow relief to aid photogrammetric study.

d) References: Zimbelman, J.R. and R. Greeley (1982) Surface properties of ancient cratered terrain in the northern hemisphere of Mars, J. Geophys. Res. 87, 10181-10189.  
Zimbelman, J.R. (1987) Spatial resolution and the geologic interpretation of martian morphology: Implications for subsurface volatiles, Icarus 71, 257-267.

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: (Name, Address, Telephone Number)  
Dr. Stanley H. Zisk  
Planetary Geosciences Division,  
Hawaii Institute of Geophysics  
2525 Correa Rd.  
Honolulu, HI 96822  
(808) 948-6488

CO-INVESTIGATORS: \_\_\_\_\_  
(Name Only) \_\_\_\_\_

PROPOSAL TITLE:  
Lunar Geologic History from High-resolution Earth-based Radar Images

ABSTRACT: List: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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a. Objectives: To continue to investigate crater impact-melt sheets by their effect on radar echo polarization, and eventually develop an age-dating technique for impact craters; to confirm the volcanian origin of dark-halo craters in Alphonsus and explore the possible existence of trapped volatiles; to analyze hi-res radar images for other geological information. b. Last year's work has not yet begun, but new data sets are available; c. This Year: Take additional images of suite of impact craters and analyze; analyze existing Alphonsus (and other) images. d. Pubs: Zisk, Campbell, and Mouginis-Mark, "Surface Morphologic Models...IGARSS '88; Simpson, Harmon, Zisk, and Thompson, "Radar Determination of Mars Surface Properties", in "Mars", (U of Ariz. Space Science Series); Garvin, Bufton, Campbell, and Zisk, "Terrain Analysis of the Meteor Crater Ejecta Blanket", LPSC XX; Campbell, Zisk, and Mouginis-Mark, "Interpreting Lava Surface Textures...", submitted

## PROPOSAL SUMMARY

PRINCIPAL INVESTIGATOR: M.T. Zuber  
(Name, Address, Geodynamics Branch, Code 621  
Telephone Number) NASA/Goddard Space Flight Center  
Greenbelt, MD 20771  
Co-INVESTIGATORS: (301) 286-2129  
(Name Only)  
PROPOSAL TITLE: Planetary Geophysics and Tectonics

**ABSTRACT:** (Type single-spaced below line. Lettered paragraphs (a) through (d) should include: a. brief statement of the overall objectives and justification of the work; b. brief statement of the accomplishments of the prior year, or "new proposal;" c. brief listing of what will be done this year, as well as how and why; and d. one or two of your recent publications relevant to the proposed work.)

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- (a) The broad objective of the proposed work is to gain insight into the mechanical structures and stress histories of the lithospheres of the terrestrial planets, with emphasis on Mars and Venus.
- (b) During the past year we have: (1) developed a suite of models that relate the regular spacings of Tharsis-related plains ridges to the shallow mechanical structure of the martian lithosphere; (2) established a basis for distinguishing whether isostatic elevation changes on Venus are a consequence of variations in crustal thickness or thermal structure; and (3) investigated models for the isostatic compensation of Aphrodite Terra, Venus.
- (c) Several general studies in planetary geophysics and tectonics are proposed: (1) an analysis of deformational instabilities in a horizontally stressed, strength-stratified lithosphere that contains a detachment surface, with the goal of better understanding the mechanics and style of tectonics on Venus; (2) the examination of faulting models for the tectonic development of martian plains ridges, in order to explore the state of stress of the martian lithosphere; (3) an assessment of the extent to which regional variations in deformational wavelengths on Venus can be interpreted as due to variations in lithosphere structure or deformational history, in order to better understand Venus' lithosphere structure; and (4) the development of models to explain stresses associated with the formation of tectonic features in the calderas of the Tharsis shields, with the goal of understanding the mechanics of these volcanic constructs.
- (d) Zuber, M.T., and E.M. Parmentier, On the relationship between isostatic elevation and the wavelengths of tectonic surface features on Venus, submitted to *Icarus*, 1989.  
Zuber, M.T., Constraints on the Lithospheric structure of Venus from mechanical models and tectonic surface features, *J. Geophys. Res.*, 92, E541-E551, 1987.





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